county's agricultural land in the County, while smaller areas of row crops occupy better soils, often in valley bottoms (Marin County Community Development Agency 2005). In contrast to the findings in 1973 that the largest threat to agricultural lands came from the potential of subdivision into suburban housing, the major issue facing agricultural lands today stems from gentrification or conversion into high value estate development (Strong Associates 2003). This conversion increases the costs of land ownership disproportionately higher than income earned from agricultural operations, thereby creating an economic disincentive for continuing to farm (Strong Associates 2003).

Geologic Resources

As with other vegetation communities, wetlands are ultimately products of geology. Geology provides the framework under which all other physical and biological forces such as water, sediment, climate, plants, and animals can interact, creating a hydrologically-driven vegetation community with special importance for both humans and wildlife. Nowhere is this more evident than in the Tomales Bay watershed. Tomales Bay and coastal Marin County have both an abundance and diversity of wetland types.

Geology has contributed to this abundance and diversity in a number of ways. Subsidence and uplift along the San Andreas Fault have created a mosaic of topographic landforms that promotes wetland establishment, including steep ravines, depressional "sag" ponds along the fault, broad floodplains, lagoons, and even isolated lakes. This fault-associated topography is juxtaposed against other geologic forces such as coastal erosion processes, which has, over the millennia, created wave-cut platforms. In combination with fault-associated uplift, coastal erosional processes have continually reshaped the northern California coastline and its associated wetlands through processes such as marine terrace building. These geologic forces have also produced a diverse array of hydrologic sources for wetlands, including tidal waters and abundant groundwater seeps and springs that serve as sources or "headwaters" for many of the bay's perennial and seasonal streams and marshes.

Subsidence and uplift along the San Andreas Fault have created a mosaic of topographic landforms that promotes wetland establishment, including steep ravines, depressional "sag" ponds along the fault, broad floodplains, lagoons, and even isolated lakes.

Geology even affects the duration of hydrology. Creeks draining off the granite-dominated Inverness Ridge tend to be perennial, while those flowing off Franciscan Complex Bolinas Ridge are seasonal or even ephemeral. The strong interaction between geology and wetlands is particularly visible within the Project Area. This relationship is discussed more in subsequent sections of this Chapter, including Water Resources and Vegetation Resources.

Geologic Resources within the Region and Project Area

The nature of the Project Area has been sharply defined by this region's unique geologic history. The sheer number of fault- and coastal erosion-associated features in this region such as trenches, shutter ridge, fault sag ponds, stream offsets, marine terraces, folded shales, sea stacks, sea caves, and pillow basalt formations has created a wealth of unique geologic resources that draw both amateur and professional geologists to Point Reyes. The San Andreas Fault, responsible for the 1906 Earthquake that devastated San Francisco, runs directly through the Project Area and Tomales Bay. The San Andreas Fault is perhaps the best known fault in California, although there are more than 20-30 other faults in the San Francisco Bay region. "It is the most significant geological feature in the watershed, influencing the geology, topography and overall stability of the area" (TBWC 2003). The San Andreas Fault Zone (SAFZ) forms the active tectonic boundary between the northwestward-moving Pacific plate and the continental North American plate.

Tomales Bay is a relatively shallow estuary that has formed within the long, linear, submerged "rift" valley that has developed along the northwest-trending San Andreas Fault zone. The Bay was formed 15,000 to 5,000 years ago when it was inundated by rising sea levels from thawed ice at the close of the last ice age (Wahrhaftig and Wagner 1972)Through the millennia, tectonic uplift or subsidence associated with plate movement, combined with other influences such as glacial retreat, has shaped the northern California coastline, with oceanic influence alternately retreating or advancing into this fault-controlled valley. At one point, what is now known as the Pacific Ocean probably extended at least as far as Point Reyes Station and probably even further inland into the Olema Valley.

Interestingly, movement along this major strike-slip fault has apparently displaced lands by as much as several hundred miles. Clark and Brabb (1997) describe similarities between Eocene and Miocene depositional sequences of the Point Reyes Peninsula and the Santa Cruz Peninsula near Monterey, California. These similarities point to displacement of the Point Reyes Peninsula along the fault by as much as 280 miles (Prentice et al. 1991; Niemi and Hall 1996). Evidence suggests that, in the past 25 million years, the Point Reyes Peninsula has been moving northward at a rate of 2 inches per year (Stoffer 2005) San Francisco's 1906 earthquake, however, caused the Peninsula to shift 12-13 inches to the north in a matter of seconds (Shuford and Timossi 1989; Evens 1993). Recent research on the San Andreas Fault has allowed researchers to document the occurrence of 10 additional large-scale land movement events in the past 2,500 years, with a recurrence interval on the order of one major event every 250 years (Zhang et al. 2003).

This movement of the Pacific and Continental Plates has produced striking differences in the geologic nature of the lands on the west and east sides of Tomales Bay. The eastern portion of the Tomales Bay watershed is dominated by the Franciscan formation (U.S. Soil Conservation Service 1985). Bedrock east of the fault (generally east of State Route 1) is the Franciscan Complex that makes up much of California's Coast Range. The Franciscan Complex is believed to be a fossil accretionary wedge of sediment that used to fill the trench of a subduction zone. It is mostly composed of greywacke, sandstone and shale with different grades of metamorphosis. Some parts of the Franciscan Complex are a mélange, including highly metamorphosed, low-grade mudstone, siltstone, and sandstone with occasional inclusions of limestone, chert, serpentinite, eclogite, and amphibolite conglomerate (Galloway 1977).

The movement of the Pacific and Continental Plates has produced striking differences in the geologic nature of the lands on the west and east sides of Tomales Bay.

Between the Bay and the Franciscan Complex hills are low-elevation coastal marine terraces that run along the eastern perimeter of Tomales Bay (Figure 20). The Point Reyes Mesa, which borders the Project Area, to the east is a marine terrace. This prehistoric wave-cut terrace consists of unconsolidated sand, clay, and gravel of marine and non-marine origin (KHE 2006a). These marine- and non-marine materials also underlay the medial or "shutter" ridge that separates the Olema Creek and Bear Valley Creek drainage to the south (KHE 2006a).

West of Tomales Bay on the steeply sloped Inverness Ridge – and within most of the Seashore – granitic rock such as quartz-diorite and granodiorite dominate, forming the backbone of the Point Reyes Peninsula (USSCS 1985; Figure 20). Salinian granite underlies nearly the entire peninsula and is exposed in the areas of Inverness Ridge, Tomales Point, and the Point Reyes Headlands. The granite is unconformably overlain by the Monterey Shale in the southern part of the peninsula which is exposed along the coastline from Drakes Bay south to Bolinas (Konigsmark 1998). Coastal wavecut benches and flooded valleys are the result of sea level fluctuations during the Pleistocene and Quaternary tectonic uplift (Scherer and Grove 2003). The Point Reyes plain, extending from Inverness Ridge west to the headlands is underlain by siltstone and mudstone of the Purisima Formation (Clark and Brabb 1997), which also occurs in the Santa Cruz Mountains.

FIGURE 20. LOCAL GEOLOGY

The Project Area itself is mapped as Quaternary-aged alluvium (KHE 2006a; Figure 20). This alluvium includes stream-borne gravel, sand, silt, and clay, as well as estuarine clay and peat ((Niemi and Hall 1996; Knudsen et al. 1999). Underlying the relatively young Quaternary alluvium that blankets the Project Area is approximately 1000 feet of older interbedded estuarine and alluvial sediments of the Olema Creek Formation (Grove et al. 1995). The closest surface outcrop of this formation is seen within the fault zone approximately 5-miles south of the Project Area. Based on composition and sedimentary structure, the Olema Creek Formation is interpreted to consist of the intermixed fluvial delta and estuary deposits, similar to the modern deposits accumulating on the Lagunitas Creek delta. Packages of fine-grained overbank and back swamp deposits with abundant carbonaceous material are also common (Grove et al. 1995). The alternations between fine- and coarse-grained deposits of this formation reflect the combined influences of subsidence along the San Andreas Fault zone and climatic variations that affect sea level (Grove et al. 1995). Knudsen et al. (1999) report that rapid changes in sediment composition consisting of "mud-over-peat contacts" are commonly associated with an abrupt relative sea-level rise that accompanies earthquake-induced subsidence.

Topographic Resources within the Region and Project Area

Lagunitas Creek Watershed

The topography within the Project Area is controlled by Inverness and Bolinas Ridge and the dominant San Andreas Fault. The Olema Valley, extending from Bolinas Lagoon to Tomales Bay, is representative of this phenomenon. The Olema Valley ranges in width from 1,500 to 7,000 feet and includes a variety of fault-associated topographic features including linear ridges and drainage patterns, parallel stream systems, offset rows of trees and fences, and a series of sag ponds. Most of the watersheds within the Olema Valley have drastically altered and unusual drainage patterns associated with the combination of stream capture and alterations to the topography caused by the strike-slip movement of the San Andreas Fault. Near their headwaters, Olema Creek and Pine Gulch Creek run parallel, but in opposite directions for nearly 2 miles. Near the head of Tomales Bay, Bear Valley Creek drains at an acute angle from Inverness Ridge (likely valley capture) and makes an abrupt turn to the north adjacent to the 1906 fault rupture, running parallel to Olema Creek until they both discharge into the Lagunitas Creek. The 120-foot medial or shutter ridge separates the two creeks (KHE 2006a).

Uplift associated with fault movement has created some relatively steep topography adjacent to the Project Area. Inverness Ridge forms the backbone of the Point Reyes Peninsula, reaching a height of 1,407 feet at Mount Wittenberg. The ridge is characterized by relatively consistent upland elevation with overly steep headwater stream systems. The only interruption in the ridge between Bolinas and Tomales Point is the 400-foot pass at Divide Meadow. Bolinas Ridge to the south of the Project Area in Olema Valley rises to approximately 800 feet in elevation. Sea level rise and retreat has created marine terraces directly east of the Project Area on the Point Reyes Mesa, with elevations ranging from 30 feet at the southern end near the Giacomini Ranch dairy facility to 80- to 100 feet above mean sea level at its northern end near Tomasini Creek (KHE 2006a).

Giacomini Ranch

Prior to 1862, a substantial amount of the Giacomini Ranch was actually open water and intertidal mudflats, with the historic coastal salt marsh concentrated in the eastern portion of the Giacomini Ranch, Olema Marsh, and the mouth of Olema Creek (PWA et al. 1993, Niemi and Hall 1996; Figure 21). This marsh complex represented a significant percentage of the existing salt marsh present at that time in Tomales Bay, with tidal influence at that time believed to extend as far south as Bear Valley during extreme storm tides (Evens 1993). However, during the latter half of the 19th century, sedimentation rates rose dramatically, resulting in rapid deltaic aggradation of coarse alluvium in the southern end of Tomales Bay (Figure 21). This increase in sedimentation probably resulted from an increase in logging and other changes in land use practices (PWA et al. 1993, Niemi and Hall 1996), but was undoubtedly exacerbated by the geologic instability characteristic of this region. It has been estimated that, between 1860 and 1950, approximately 5 vertical feet of sediment deposited within southern Tomales Bay (PWA et al. 1993). Acreage of wetlands within Tomales Bay almost doubled between 1863 and 2001 to 944.2 acres (Parsons et al. 2004), and the Lagunitas Creek delta more than doubled in acreage and length during this period, with the tip of the delta extending approximately another 2,100 feet beyond its 1863 boundaries by 2001. The greatest sedimentation occurred between 1860 and 1910 (PWA et al. 1993; Figure 21).

Surface rupture in Olema, 1906

The 1906 earthquake may have subsequently “drowned” some of this deltaic aggradation. The surface rupture caused by the 1906 earthquake extended from Bolinas Lagoon to Tomales Bay, with lateral displacement ranging from 14 to 20 feet in the Olema Valley (Gilbert 1908)Levee Road reportedly was offset 20 feet over a zone of faulted ground that was 50 to 60 feet wide. In addition, the roadway embankment within the fault zone reportedly settled as much as 3.5 feet. The surface rupture of the earthquake extended across the Project Area and reportedly was marked by an approximately 50-foot-wide, 18-inch-deep depression in the tidal marshes along the northeast side of the fault (Lawson 1908; Youd and Hoose 1978). Within the Lagunitas Creek delta, sag portions of the trace often appeared as “water lanes:” indeed, the “water lane” depicted as occurring directly north of the Giacomini Ranch in the undiked marsh corresponds almost exactly to the location of an existing, extremely straight tidal marsh channel. During the earthquake, a large portion of the Lagunitas Creek delta “was thrown … into gentle undulations, the difference in height between the swells and hollows being usually less than a foot” (Gilbert 1908). The undulations were not observed along the eastern shore of the bay or in the “the firmer part of the Papermill delta…” (Gilbert 1908). The horizontal shifting of the mud flats occurred over an approximate distance of 1.5 miles along the western margin of the bay, with the observed northern limit near the town of Inverness. Wave action gradually smoothed out the ridges and troughs, but some of the larger troughs remained, ranging in height from 1 to 3 feet or more (Gilbert 1908). This undulation may explain some of the localized losses of salt marsh habitat that were reported within Tomales Bay (Gilbert 1908).

Despite the earthquake, sedimentation and deltaic aggradation continued to be high until at least the 1950s, when construction of several dams and reservoirs began to curtail sediment delivery (Figure 21). These dams include the Peters and Lagunitas Dams, which control about 70 percent of the Lagunitas Creek watershed (PWA et al. 1993). By the early 1940s, rapid sedimentation had converted this marsh from the tidally dominated system depicted in the 1863 map to a fluvial or creek-dominated one, with remnants of the tortuously meandering sloughs once present and characteristic of tidal systems restricted to the eastern perimeter of what would become the East Pasture. The rapid delta formation at Lagunitas Creek encouraged the Giacominis to dike approximately 550 acres of the historic and newly created marsh in 1946 for creation of the Giacomini Ranch. Since diking, topography of the Giacomini Ranch has largely been affected by land-leveling activities, efforts to re-direct flood and creek/drainage flows, and sediment deposited during flooding. Elevation of the levees is highly variable due to maintenance activities and erosion- and cattle-related degradation.

Displacement of Levee Road following 1906 earthquake

FIGURE 21. HISTORIC MAP OF SOUTHERN TOMALES BAY

The topographic map prepared by the (USGS 2003b) indicates that the majority of the active pasturelands are relatively flat, having an average elevation of 4-feet NAVD88 in the East Pasture and 5-feet NAVD88 in the West Pasture (KHE 2006a). The highest ground elevations (up to about 30-feet NAVD88) occur at the Giacomini Dairy facility in the southeast corner of the Ranch (KHE 2006a). The lowest elevations on the map (about 0-feet NAVD88) correspond to bed elevations in interior drainage channels in both the East and West Pastures and portions of Lagunitas Creek between the two pastures (KHE 2006a). In general, the East Pasture is highest along the south margin (11- to 16 feet NAVD88) and slopes down to the average pasture elevation of 4-feet approximately at a distance of approximately one-quarter of the pasture length to the north (KHE 2006a). This sloping surface is part of two similar geomorphic features, one being the face of a natural alluvial fan building out onto the historic marsh plain from the mouth of Lagunitas Creek and the other being a wedge of fine grained sediment splayed onto the East Pasture through a low spot in the levee during repeated flooding (KHE 2006a). The East Pasture is essentially flat over its northern three-quarters (KHE 2006a).

The east half of the West Pasture (located immediately west of the Lagunitas Creek levee) slopes gently and evenly from approximately 8-feet NAVD88 at the south end to 5-feet NAVD near the North Levee (KHE 2006a). Ground surface elevations along the western margin of the West Pasture and along Sir Francis Drake Road range from 14-feet NAVD88 (at the south end) to 21-feet NAVD88 (at the north end; KHE 2006a). Topography is heavily influenced by alluvial fans that have formed at the mouths of several creeks that discharge onto the West Pasture along the base of Inverness Ridge (KHE 2006a). The crest of the West Pasture levee averages about 12 feet NAVD88 in elevation at the south end and 10 feet NAVD88 at its intersection with the north levee (KHE 2006a). The north levee of the West Pasture has an average elevation of approximately 10 feet NAVD88. Along this same span, the East Pasture levee crest is typically about 2 feet lower in elevation than the West Pasture levee (KHE 2006a). Concrete spillways approximately 180-feet long with crest elevations around 7.5-feet NAVD88 occur at the north end of both the East and West Pastures (KHE 2006a). These structures are designed to drain seasonal floodwaters from each pasture.

Topographic information collected by the USGS suggests that, unlike San Francisco Bay marshes, diking in the Project Area has not resulted in extensive subsidence or lowering of elevations within the Giacomini Ranch. In San Francisco Bay, marshes largely developed from organic- or peat-rich clay materials that rapidly compacted once levees were constructed between the 1860s and 1960s. The base elevation of diked marshes in San Francisco Bay is often 7- to 12- feet below that of undiked areas, and subsidence is even greater in the Sacramento Delta, often ranging between 15- to 20-feet.

Conversely, along the outer San Francisco Bay coast, there was a period of rapid marsh formation in the late 1860s and early 1900s in response to increased sedimentation within watershed tributaries. Many of these "young" marshes were largely composed of low-organic coarse alluvial mineral soils that have compacted little, if at all, if and when these marshes were diked (Parsons et al. 2004). Elevations of the adjacent undiked marsh to the north of the Giacomini Ranch range from +3 (low marsh) to +7 feet (high marsh/upland ecotone) NAVD88, with the marsh plain at approximately +5 to +6 feet NAVD88 (USGS 2003b). This information suggests that elevations behind or inside the levees have decreased, at most, 1 foot at the northernmost portions of the Giacomini Ranch and have aggraded within the southernmost portions. Some of the aggradation may result from land leveling and deposition of fill and manure, but the Giacominis also removed the southwestern portion of the East Pasture levee deliberately to preferentially direct flood flows into this portion of the property (KHE 2006a). This dynamic is illustrated in Figure 22, which shows higher elevation areas that would not be subject to tidal flooding even if levees were not present in green: Subtidal and lower intertidal areas exist only in existing creeks, sloughs, and ditches.

Olema Marsh and Lower Bear Valley Creek

A 2004-2005 series of topographic surveys of Olema Marsh and lower Bear Valley Creek also revealed that elevations were higher than originally anticipated, at least in Olema Marsh. The center of Olema Marsh ranged in elevation from approximately +4 - to +8 feet NAVD88 (KHE 2006a). Meanwhile, the elevations of the adjacent Levee Road range from +11- to +13 feet NAVD88, approximately the same elevation as the county's White House Pool park on the north side of Levee Road (KHE 2006a, USGS 2003b). Upstream of Olema Marsh, lower Bear Valley Creek gradient remains flat for 3,000 feet upstream of Olema Marsh and then starts rising gently with a 1 percent grade to the Seashore's maintenance facility area (KHE 2006a).

In 1982, Bear Valley Creek underwent some very dramatic topographic changes as a result of the 1982 flood, a 100-year storm, and clean-up efforts from debris flows after the storm. Prior to the storm, the middle and lower portions of the Bear Valley Creek channel had become deeply incised. During New Year's, 1982, a rainfall total of 11-20 inches was recorded within 24 hours. As a result of these excessive rains and high soil saturation, many of the drainages originating from Inverness Ridge broke loose, resulting in catastrophic debris flows (Ellen et al. 1988). Debris flows originating in the two major tributaries of Bear Valley Creek carried into the mainstem of Bear Valley Creek, choking the former channel, scouring existing road/trail facilities, and turning the colluvial valley bottom into a sandy, braided stream channel with extensive woody debris jams that acted to temporary dam and pond waters within the channel. The lower portion of Bear Valley Creek rapidly went from an incised channel with steep creek banks and no connection to the adjacent floodplain terrace to a swampy marsh that, in some areas, has no defined channel.

Interestingly, the higher-than-anticipated elevations within Olema Marsh do not appear to be related to excessive sedimentation following the 1982 flood or the smaller, but still significant 1998 flood, as was expected (KHE 2006b). The lower section of Bear Valley Creek appears to be comprised entirely of peat derived from tules and cattails that is at least 10 feet deep (KHE 2006a). The flattening of the valley gradient and the berm effect caused by Bear Valley and Levee Roads has contributed to an increase in water residence time and water depth in the lower Bear Valley reaches. Persistent ponding within the creek and marsh encourages build-up of peat within lower Bear Valley Creek and Olema Marsh by precluding oxidation of organic matter, which may be causing marsh surface elevations to increase and contributing to the increase in water depth. Sedimentation that has occurred in Olema Marsh appears to be due more to anthropogenic activities. A large rectangular swath of land within the northern portion of the marsh appears to have been graded and leveled along Levee Road, obliterating some of the remnant slough channel features that were still apparent in 1961 aerial photographs (KHE 2006b).

The central portion of Olema Marsh lies at an elevation between 4- and 6-feet NAVD88 (KHE 2006a). The marsh plain elevation upstream of Bear Valley Road starts at approximately 6-feet (NAVD88) and gradually slopes upward for a distance of 1600-feet to an elevation of approximately 9-feet NAVD88 (KHE 2006a). Moving upstream of this point, the valley bottom steepens, and the creek channel occupies a well-developed channel within a broad floodplain. There are no levees on the south side of Lagunitas Creek between Green Bridge and White House pool to protect Levee Road or existing residences from flooding. As its name implies, Levee Road acts as a levee itself. The crest of Levee road is concave in shape, with roadway high points of 12.5- and 13.2-feet NAVD88 at the east and west ends where it borders Olema Marsh and falling to 11.6-feet midway in between. Similarly, Bear Valley Road is an earthen berm with 60-foot top-width, bisecting a lower portion of Bear Valley Creek and bordering the south- and western margins of Olema Marsh.

Crest elevation of Bear Valley Road range from 15.6- to 14.6-feet NAVD88 and is approximately 7- to 8-feet above the marsh plain surfaces in lower Bear Valley Creek and Olema Marshes.

Geologic Resource Issues - Geologic Hazards

Regulatory and Policy Setting

The devastating impacts of large earthquakes on urban and rural communities and potentially even parks have led to development of various Park Service, state, and local policies and regulations that are aimed at minimizing risks to residents and visitors. Within California, several policies and regulations apply to geologic hazards and geotechnical practice in the San Francisco Bay region. These include the California Alquist-Priolo Earthquake Fault Zoning Act, the Seismic Hazards Mapping Act, the Uniform Building Code, as well as county regulations that address geologic hazards as they relate to grading and construction activities.

While the Park Service is charged to preserve geologic processes "unimpaired," natural geologic processes "can be hazardous to humans and park infrastructure," so park managers must strive to understand future hazards and, once understood, "minimize their potential impact on visitors, staff, and developed areas" (NPS 2001, Section 4.8.1.3). Management policies also direct the Park Service to "try to avoid placing new visitor and other facilities in geologically hazardous areas" (NPS 2001a, Section 4.8.1.3).

FIGURE 22. INTERTIDAL ELEVATIONS

California's Alquist-Priolo Earthquake Fault Zoning Act (California Public Resources Code Section 2621 et seq.) prohibits the location across the traces of active faults of most types of structures intended for human occupancy and strictly regulates construction in corridors along active faults (earthquake fault zones). The Act is intended to reduce the hazard to life and property from surface fault ruptures during earthquakes. It also defines criteria for identifying active faults and establishes a process of review for building proposals in and adjacent to earthquake fault zones. Under the Alquist-Priolo Act, faults that are characterized as "sufficiently active" and "well-defined" are zoned differently, and construction in these zones is regulated more stringently. A fault is defined as "sufficiently active" if one or more of its segments or strands show evidence of surface displacement during Holocene time (approximately the last 11,000 years). The San Andreas Fault Zone (SAFZ) is the only known on-land "active fault" and only zoned fault within the boundaries of Marin County (Snyder and Smith Associates Inc. and Nichols-Berman 2002). Local agencies are responsible for regulating construction within Alquist-Priolo Zone, including all land divisions and most structures for human occupancy except single family wood-frame and steel-frame dwellings up to two stories that are not part of a development of four or more units (California Geological Survey 2006). Cities and counties cannot approve development unless a geologic investigation is performed by a licensed geologist.

While the Alquist-Priolo Act specifically addresses hazards associated with surface fault rupture, the Seismic Hazards Mapping Act of 1990 (California Public Resource Code Sections 2690-2699.6) specifically focuses on other hazards related to earthquakes such as ground shaking, liquefaction, and seismically induced landslides. Through this Act, the state is charged with identifying and mapping areas at risk of strong ground shaking, liquefaction, landslides, and other corollary hazards. Cities and counties are required to regulate development in mapped seismic hazard zones through requiring appropriate site geologic and soil investigations and mitigation measures as part of permit review. Further support for review of construction within geologically hazardous areas comes from the State of California's minimum standards for structural design and construction are given in the California Building Standards Code (CBSC) (CCR Title 24).

The LCP for Zone II, in which the Project Area is located, states that in Alquist-Priolo Zones, earthquake hazard zones, and areas subject to liquefaction, landslides, bluff erosion, and steep slopes averaging greater than 35 percent, proposed projects will be "required to demonstrate that the area of construction is stable for development, the development will not create a hazard or diminish the stability of the area, the" (Marin Community Comprehensive Planning Department 1981). Furthermore, the Coastal Resources and Management Policies requires that proposed projects in the Coastal Zone must "minimize risks to life and property in areas of high geologic…hazard" (Section 30253). The Point Reyes Station Community Plan (Marin County Community Development Agency 2001) also has developed policies relating to changes in topography that might affect geologic substructures or unstable soil conditions or unique geologic or physical features.

Geologic Hazards within the Project Area

Earthquakes. As described earlier, the Project Area is particularly vulnerable to geologic hazards due to being sited directly on the San Andreas Fault, certainly one of the most famous, if not necessarily the most active, of California's faults.

During the last 160 years, the San Andreas Fault system has produced numerous small-magnitude and a dozen moderate to large (magnitude>6) earthquakes in the San Francisco Bay Area (USGS 2003a) although there have been no extremely large earthquakes on the northern section of the fault since 1906. The Loma Prieta earthquake, the most recent catastrophic event in the Bay region of the SAFZ, occurred in 1989 in the Santa Cruz Mountains approximately 8.7 miles north of Santa Cruz. It caused tremendous damage, including collapse of a portion of the Oakland Bay Bridge. The San Andreas Fault is the only fault within Marin County mapped as being in an Alquist-Priolo Earthquake Hazard Zone, and the boundaries of this "zone" incorporate the Project Area (Figure 23).

The San Andreas Fault is not the only active fault in the Point Reyes area (Figure 23). The Project Area is also located near the offshore Point Reyes fault, which is identified as a Type B seismic source[1] by the current

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1 The UBC evaluates the risk associated with active faults based on their potential to generate large earthquakes (measured as the moment magnitude for the largest earthquake anticipated on the fault) and their degree of seismic activity (measured as average annual slip rate). Under this system, a *Type A seismic source* is a fault that is capable of producing large-magnitude events ($\geq$ M 7.0) and is highly active (has a

Uniform Building Code (UBC) (International Conference of Building Officials 1997), although it is not zoned by the State of California. The San Gregorio Fault runs in the ocean from Santa Cruz to Point Reyes. The northern extent of the North Hayward fault is located a considerable distance east of the Project Area in the eastern portion of San Francisco Bay. The Rodgers Creek fault, which is the likely northward continuation of the North Hayward fault trend, is located in Sonoma County 25 miles northeast of the Project Area. Both of these faults are zoned by the state and are identified as a Type A seismic source by the UBC (Hart and Bryant 1997; International Conference of Building Officials 1997). Table 3: Faults summarizes current estimates of the maximum earthquake anticipated on the principal active faults in the vicinity of the Project Area.

TABLE 3. MAXIMUM EARTHQUAKE ANTICIPATED ON MAJOR FAULTS IN VICINITY OF POINT REYES NATIONAL SEASHORE

Fault	Estimates of Maximum Earthquake	Estimated Mean Recurrence Interval[b]
San Andreas (northern segment)	7.9[a] 7.45[b]	223 years
Rodgers Creek	7[a] 6.98[b]	205 years
Point Reyes	6.8[a]	Unknown

Sources: [a]International Conference of Building Officials 1997, [b]U.S. Geological Survey Working Group on California Earthquake Probabilities.

Geologists have found that earthquakes do not occur randomly, but rather are clustered, because as strain is released in one area, it may actually increase in another (USGS 2003a). This clustering has led geologists to estimate that the probability of an earthquake of magnitude 6.8 or larger occurring during the next 30 years in the San Francisco Bay region is approximately 62 percent (USGS 2003a). The probabilities of an earthquake with a magnitude greater than 6.7 between 2000 and 2030 are 21 percent for the San Andreas Fault and 32 percent for the Hayward-Rodgers Creek fault (USGS 2003a).

Earthquakes are associated with several major hazards: ground shaking, surface fault or ground rupture, ground failure (e.g., liquefaction, settling, and lurching), landslides, and inundation from tsunamis or tidal waves or waves in enclosed water bodies such as lakes and reservoirs. The potential for a surface fault rupture or ground rupture is limited to areas along the fault or within 250 feet of the fault, which means that the risk of surface fault rupture is extremely high, as the Project Area lies directly over the San Andreas Fault. The risk for tsunami or tidal wave might be considered high, as well. Tsunamis are long period waves that are typically caused by underwater disturbances such as landslides, volcanic eruptions, or seismic events. Areas highly susceptible to tsunamis are low-lying coastal areas such as tidal flats, marshlands, and diked areas that are still at or near sea level. However, the Point Reyes Peninsula and the distance of the Project Area from the mouth of the Bay afford it protection from tsunami-causing events in the open ocean (Anderson Consulting Group 2000; EDAW Inc. 2001).

high average annual slip rate). A *Type B seismic source* is associated with smaller maximum event and/or is less active, but still constitutes a substantial seismic threat (International Conference of Building Officials 1997).

FIGURE 23. EARTHQUAKE HAZARDS

In general, the destructiveness of earthquakes to humans namely, injury, loss of life, and property damage, are influenced by epicenter proximity, earthquake magnitude, a given structure's resistance to earthquakes (e.g., modern structures are constructed so that they flex during earthquakes), and the substrate or geologic materials upon which a structure is built. The Modified Mercalli Intensity Scale is an earthquake shaking intensity scale based on local effects experienced by people, structures, and earth materials based on the damage and havoc created during the 1906 earthquake. Created in 1931, this scale ranges from I, which is an event not felt by people to XII, which are events that cause general panic and total damage. The 1906 earthquake produced ground shaking of Modified Mercalli Intensity VIII to IX in the vicinity of the fault (Wald et al. 1993). Because of its proximity to an active fault, the Project Area has been characterized as occurring in an area with a Mercalli Intensity Shaking Severity Level of X, which are events that are Very Violent (Association of Bay Area Governments (ABAG) 2003). The Earthquake Hazard rating for the Project Area was also the severest one possible (ABAG 2003; Figure 23), classified as regions are near major, active faults that will on average experience stronger earthquake shaking more frequently. This intense shaking can damage even strong, modern buildings.

In addition to proximity, substrate also plays a crucial role in determining the amount of destruction caused by earthquakes. For example, while the 1906 earthquake is often referred to as the San Francisco earthquake, the city of San Francisco does not directly straddle the San Andreas Fault. One of the reasons that the 1906 earthquake was so destructive in San Francisco is that much of the city was built upon imported sand fill that became unstable during plate movement. Loose, saturated materials such as sands can become fluid-like during an earthquake, suddenly losing strength and behaving almost like quicksand. This phenomenon, called liquefaction, typically occurs where groundwater is shallow and the substrate is clean, poorly consolidated, loose sand. Other phenomena include ground lurching or horizontal movement of ground located adjacent to slope faces and lateral spreading, horizontal displacement of soil that occurs in loose, unconfined sedimentary and fill deposits.

Seismic hazard maps have not been issued for the any of the quadrangles in the vicinity of the Project Area (California Geological Survey 2004). However, generalized liquefaction hazard level mapping available characterizes the liquefaction hazard level or susceptibility within the Project Area as being High (ABAG 2003; Figure 24) or Very High (Knudsen et al. 2000). The Project Area occurs within what has been mapped as Quaternary alluvium, which consists of stream-borne gravel, sand, silt, and clay, as well as estuarine clay and peat (Knudsen et al, 1999, Niemi and Hall 1996). The groundwater table beneath the entire Project Area is very shallow, often within 1-4 feet of the ground surface even during the summer (NPS, unpub. data). Bedrock was not encountered within any of the shallow soil borings conducted by KHE (2006a).

At least six liquefaction events have been documented within the Project Area in the past, most of which involved cracks in the ground without other effect, although one instance included lateral spread and ground settlement (Youd and Hoose 1978). Not only is this type of substrate subject to liquefaction, but it tends to amplify the energy of earthquakes. The National Earthquake Hazards Reduction Program (NEHRP) has defined five soil types on the basis of their shear-wave velocity or the velocity at which the rock or soil transmits shear waves. Shaking is stronger where the shear wave velocity is lower. Because the Project Area contains water-saturated mud and artificial fill, it has been mapped as having velocities of less than 200 m/sec, which would provide the strongest amplification of shaking (ABAG 2003).

The seismic hazard conditions present in the Project Area also have implications for the integrity of earthen structures such as levees, which are more prone to failure or breaching when near an earthquake fault or in areas that are rated as having high susceptibility to liquefaction, ground lurching, or settlement. Ground shaking is the primary cause of earthquake damage to human-made structures, including levees.

FIGURE 24. LIQUEFACTION SUSCEPTIBILITY

Landslides. Landslides can be induced by both earthquakes and excessive rainfall. While the Seashore and north district GGNRA lie on one of the more infamous North American faults, the recent physical history of this area appears to have been influenced more by watershed-scale sediment movement precipitated by either anthropogenic disturbance or natural, catastrophic flooding. As discussed earlier, denuding and ground disturbance associated with logging, agriculture, grazing, and other settlement activities appears to have destabilized already unstable hillslopes that subsequently increased the potential for erosion and landslides during moderate to large rainstorms. This sediment then washed down from the upper portions of the watershed into the mouth of Tomales Bay, forming the Lagunitas Creek delta. Since then, natural flood or other catastrophic events such as the 1982 (100-year), 2006 (30-year), and 1998 (10-year) floods and the 1996 Mt. Vision fire has continued to shape Tomales Bay and the Lagunitas Creek subwatershed, particularly the lower Bear Valley Creek and Olema Marsh areas (Anima et al. 1988). Each of these events led to mobilization of enormous amounts of sediment from landslides within the Seashore's watersheds, including the Lagunitas Creek, Olema Creek, and Bear Valley Creek watershed.

The danger from landslides is directly related to the geologic stability of the surrounding landscape. The Franciscan Complex, which runs along the eastern portion of the Tomales Bay watershed, including the Bolinas Ridge, is known for slope instability, thin soils, and high runoff rates. Similarly, the deeper soils on the granite-dominated Inverness Ridge can also be unstable, often leading to massive landslides during large storms that create catastrophic debris and sediment flows. As noted earlier, the Seismic Hazard Zone mapping has not been completed for Marin County (California Geological Survey 2004). However, the USGS (1997)has created a summary distribution map of slides and landflows within the San Francisco Bay region based on historic occurrences of landslides and landflows.

The Project Area itself is mapped as "flatland" and therefore not prone to landslide (USGS 1997). More than 70 percent of the eastern portion of the Tomales Bay watershed, however, is mapped as "Mostly Landslide," with the intervening areas mapped as "Few Landslides" (USGS 1997). The western portion of the watershed -- specifically the eastern portion of the Inverness Ridge draining to Tomales Bay -- is mapped largely as "Few Landslides," with a few pockets or areas representing less than 5 percent of the area characterized as "Mostly Landslide" (USGS 1997). However, anecdotal information from Inverness Ridge residents and local agencies responsible for culvert maintenance suggest that at least the portion of the Ridge adjacent to the Project Area erodes easily, with moderate amounts of sedimentation occurring in most average rainfall years and excessive amounts occurring during wet years.

Geologic Resources and Wetland Functionality

Perhaps, the most critical role that geology plays with regards to wetlands is formation and maintenance. Nowhere is this more evident than in Tomales Bay, which owes it very existence to the San Andreas Fault. However, geology can also influence wetland attributes such as functionality in a number of ways. For example, moderately abundant groundwater in this region provides water sources for municipal and private water supply and recharges surface water in creeks and other water bodies during the summer, which improves habitat quality for wildlife. The headwaters for many of the small drainages on the Inverness Ridge are seeps and springs, in addition to surface run-off, and seeps and springs that emerge at the base of hills serve to increase wetland diversity through increasing hydrologic complexity. From a formation perspective, faults act somewhat as an equalizing agent, with earthquake-induced subsidence counteracting to some degree the inherent tendency of tidal wetlands to evolve toward upland conditions over time due to sediment deposition on marshplains.

Soil Resources

While functions performed by wetlands are considered "hydrologic" or "biological," soils are integral components to almost all of these ecosystem services. Soils bind and transform nutrients and contaminants within floodwaters, which is critical for wetlands' ability to improve water quality. Plants, obviously, need soil to grow, and plants are important to both floodwater retention and water quality improvement through dissipating flood flow energy and allowing sediment, nutrients, and contaminants to drop out of the waters onto the floodplain. Much of the carbon that is exported to source waters such as bays and estuaries does not come directly from plants, but from plant and animal matter that is broken down in the soil into forms of organic matter that can be better assimilated by estuarine and marine organisms. While resident and non-resident wildlife use plants for foraging, protection, nesting, and resting, soil itself is an important wildlife habitat. Benthic and benthic stages of invertebrates burrow in mudflats, while species such as the northwestern pond turtle (*Clemmys marmorata marmorata*) aestivate in dry, sandy upland soils. Without soils – and, more importantly, a functioning soil environment – most wetlands would not be able to perform some of their vital functions.

Soils bind and transform nutrients and contaminants within floodwaters, which is critical for wetlands' ability to improve water quality.

Soil Resources within the Project Area

Soil types mapped within the Giacomini Ranch and Olema Marsh are consistent with this area's unique geologic history. The Marin County Soils Survey provides generalized baseline information on soils within the project area (U.S. Soil Conservation Service (USSCS) 1985). Soils are classified into broad associations comprised of one or two major soil types, from which the name of the association is taken, and several minor soil types.

The northern 60 percent of the Giacomini Ranch and most of the Olema Marsh are comprised of Novato Clay (USSCS 1985; Figure 25). Novato Clay is described as "very deep, very poorly drained soil…in saltwater marshes …formed in alluvium derived from various kinds of rock" (USSCS 1985). The historic coastal salt marsh in the southeastern corner of the Giacomini Ranch and the portion of Lagunitas Creek along Levee Road is mapped as Blucher Cole complex (USSCS 1985; Figure 25). The Blucher-Cole complex is also formed in alluvium from various kinds of rock, although this mapping unit is typically found in basins and on alluvial fans. Both components of this mapping unit are characterized as very deep soils that are somewhat poorly drained with seasonally high water tables and occasional periods of flooding (USSCS 1985). The southernmost portion of Olema Marsh, as well as the portion of Bear Valley Creek flowing into the Marsh, consists of fluvents, channeled, a hydric soil complex commonly formed in floodplains (USSCS 1985; Figure 25).

Soil borings conducted as part of the proposed project indicate, however, that soil patterns within the Giacomini Ranch and Olema Marsh are much more complex than the soil map would suggest. The historic salt marsh areas in the southern and eastern portions of the East Pasture typically consist of intermixed estuarine clays and peats overlain with a thin (~0.3 –0.5 m) loam or clayey loam layer (KHE 2006a). The very southern portion of the East Pasture has a very thick (2.5 m) accumulation of fluvially derived, interbedded silt and sand (KHE 2006a).

Conversely, sediment in many of the historic subtidal areas in the East Pasture that are directly adjacent to historic and current Lagunitas Creek channels are comprised of loam or silty loam overlain by interbedded silt, clay, and sand (KHE 2006a).

FIGURE 25. SOIL TYPES

Based on an understanding of surrounding geologic materials and the mode of their deposition, the shallow stratigraphy underlying the site includes depositional facies of alluvium (fluvial and alluvial fan deposits) bordering, overlying and/or interfingering with a variety of estuarine (marsh plain) deposits (KHE 2006a). The youngest deposits encountered consist of alluvial silts and fine-grained sands that blanket much of the southwest corner of the East Pasture. These sediments were deposited by floodwaters entering the East Pasture through the low spot in the Lagunitas Creek levee located between White House Pool and the fall summer dam. These sediments were deposited since reclamation of the site in the mid-1940s and overlie preexisting estuarine clays and peats representative of an intertidal high-marsh complex. Estuarine clays and peat deposits underlie the majority of the East Pasture and are capped in other locations by fill material and possibly alluvial fan materials at the historic mouth of Tomasini Creek. Unlike most estuarine deposits, which are high in organic matter, these soils had very low organic content, which, again, may be the reason that this area has not subsided as a result of diking (KHE 2006a).

In the West Pasture, a thin veneer of silty loam rests on a thick sequence of extremely permeable coarse-grained sands and gravels (KHE 2006a). The coarse-grained material probably marks the historic alignment of Lagunitas Creek or reflects near-channel accumulation of bedload and suspended sediment deposited during storm events (KHE 2006a). The texture and depositional relationship of the bulk of these deposits reflect a fluvial- or creek- dominated system displaying course-grained channel bed and bar deposits, fine-grained (silt and clay) overbank or floodplain deposits, and terrestrial organic matter representative of the freshwater marshes on the perimeter of the West Pasture. The northernmost portion of the West Pasture displays estuarine, organic-rich clay and peat, materials reflecting the current tidal and estuarine influence that now dominates this area. Although no soil borings were completed in the higher-elevation alluvial fans on the western perimeter of the West Pasture, site topography and observations of surface materials indicate well developed alluvial fans comprised of angular, coarse-grained sand to fine-grained granitic gravel emanating from the mouths of creeks draining the Inverness Ridge and overtopping and interfingering with fluvial and estuarine deposits (KHE 2006a).

Recent borings in lower Bear Valley Creek show an entirely different soil substrate in this area, with the substrate dominated by very thick beds (8-10 feet) of peat with a thin stratum of fine-grained clays on the surface (KHE 2006a). Thick deposits of shallow peat were also encountered by the County of Marin at the northwest corner of Olema Marsh while completing sediment removal excavations in the Levee Road drainage ditch feeding the western culvert outfall from the marsh (Liz Lewis, County of Marin, *pers. comm*.). Thus, it is inferred that these same shallow peat deposits dominate beneath the intervening Olema Marsh area (KHE 2006a). The historically marshy nature of this low gradient portion of the creek, combined with sustained water ponding in more recent times from damming of the marsh by levees, culverts, and gravel sills, has dramatically reduced breakdown of organic matter. Some creek-borne sand, clay and silt flood plain deposits were encountered with thin interbedded layers of terrestrial vegetation in the most upstream soil boring locations (KHE 2006a).

In summary, shallow soil stratigraphy reflects very well the hydrologic environments depicted in 1862 National Geodetic Survey map, which shows the historic alignment of Lagunitas Creek being through what is now the West Pasture, while the East Pasture, Olema Marsh, and lower Bear Valley Creek appear as estuarine tidal marsh.

Soil Resource Issues - Prime and Unique Farmland Soils

Regulatory and Policy Setting

The federal Farmland Protection Policy Act (FPPA) is intended to minimize the impact federal programs have on the unnecessary and irreversible conversion of farmland to non-agricultural uses. For the purpose of FPPA, farmland includes prime farmland, unique farmland, and land of statewide or local importance, which is characterized primarily using soil types, as well as management regimes and other factors. Farmland subject to FPPA requirements does not have to be currently used for cropland. It can be forest land, pastureland, cropland, or other land, but not water or urban built-up land. California's Farmland Monitoring and Mapping Program was established in 1982 to assess the location, quality, and quantity of agricultural lands and conversion of these lands over time. FMMP is a nonregulatory program and provides an analysis of agricultural land use and land use changes throughout California every two years. Under Public Resources Code Section 21060.1 of CEQA, the FMMP is used to define agricultural land for the purposes of assessing CEQA environmental impacts to agricultural lands. A more detailed description of land use policies related to agriculture can be found under the Land Use and Planning section. Because the Prime and Unique Farmland Soils designation is still largely a soil-related characterization, the areal extent of Prime and Unique Farmland Soils is discussed under Soil Resources.

Prime and Unique Farmland Soil Resources within the Project Area

The most recent version (2004) of the Important Farmland map of Marin County shows the Giacomini Ranch and Olema Marsh as having several important farmland soil types (California Department of Conservation 2004). The definitions for Prime Farmland, Farmland of Statewide Importance, Unique Farmland, Farmland of Local Importance, and Urban Built-up Land were developed by the U.S. Department of Agriculture (USDA) – Soil Conservation Service (SCS) as part of its nationwide Land Inventory and Monitoring (LIM) system. These LIM definitions have been modified for use in California by the California Department of Conservation, which oversees the Farmland Mapping and Monitoring Project (FMMP). The most significant modification is that Prime Farmland and Farmland of Statewide Importance soil types must be irrigated to qualify as important farmland. Farmland of Local Importance is identified by local advisory committees and varies from county to county, as intended by the LIM. Mapping of Grazing Land as part of an Important Farmland Map is unique to California. The California Department of Conservation has established a minimum mapping unit of 10 acres unless otherwise specified, with units of land smaller than 10 acres incorporated into surrounding map classifications.

Within the Project Area, the southeastern 133.2 acres of the Giacomini Ranch East Pasture was currently mapped as Farmland of Statewide Importance (California Department of Conservation 2004; Figure 26). The entire Giacomini Ranch West Pasture, the northernmost and easternmost portion of the East Pasture, the very westernmost portion of White House Pool County Park, and Olema Marsh are mapped as Grazing Land, totaling 293.2 acres (California Department of Conservation 2004). The remainder (136.4 acres) of the East Pasture and the White House Pool County Park are mapped as Farmland of Local Importance (California Department of Conservation 2004; Figure 26).

Farmland of Statewide Importance is land other than Prime Farmland which has a good combination of physical and chemical characteristics for the production of crops (California Department of Conservation 2006). It must have been used for the production of irrigated crops at some time during the two update cycles prior to the mapping date. It does not include publicly owned lands for which there is an adopted policy preventing agricultural use. Farmland of Statewide Importance must meet all the following criteria: water, soil temperature, acidity-alkalinity, water table, soil sodium content, flooding, erodability, and rock content. Soils in the southeastern portion of the Giacomini Ranch qualified as Farmland of Statewide Importance soils, because the soil type, Blucher-Cole complex, 2 to 5 percent slopes, is one of several designated Farmland of Statewide Importance soil types.

Also, this area is currently irrigated for pasture purposes, which qualifies as “crops” for Prime Farmland and Farmland of Statewide and Local Importance designations, but not the Unique Farmland designation (M. Penberth, California Department of Conservation, *pers. comm.*). Important Farmland maps depict the Project Area as accounting for a moderately high percentage of the Farmland of Statewide Importance soils mapped in Marin County (~30 percent). However, this number is somewhat misleading as Giacomini Ranch only represents 2 percent of the total acreage of Blucher-Cole complex soils mapped in Marin County. A large percentage of the other Blucher-Cole complex soils appear to be mapped as Farmland of Local Importance Soils or Grazing Land probably because, while they are grazed such as East Pasture, they are not irrigated. Most Farmland of Statewide Importance soils are probably irrigated for row crop or sillage, rather than pasture, purposes.

Farmland of Local Importance is either currently producing crops, has the capability of production, or is used for the production of confined livestock (California Department of Conservation 2006). Farmland of Local Importance is land other than Prime Farmland, Farmland of Statewide Importance or Unique Farmland. This land may be important to the local economy due to its productivity or value. It does not include publicly owned lands for which there is an adopted policy preventing agricultural use. Farmland of Local Importance is initially identified by a local advisory committee (LAC) convened in each county by FMMP in cooperation with the USDA-SCS and the county board of supervisors.

FIGURE 26. FARMLAND SOIL TYPE

In Marin County, Farmland of Local Importance is defined as land that is not irrigated, but cultivated or has the potential for cultivation (California Department of Conservation 2006). In the Project Area, Farmland of Local Importance strongly overlaps with areas mapped as Novato Clay, although Local Importance soils are not necessarily linked to a particular soil type. Farmland of Local Importance has been mapped in the northern portions of the East and West Pastures, Olema Marsh, and portions of White House Pool County Park. In 2000, almost all of the areas with Novato Clay soils were designated as Farmland of Local Importance, however, some of these areas in the East and West Pasture have been reclassified in the 2004 map as Grazing Land, probably because of the poor likelihood for crop production given the persistent ponding during winter and spring and high residual soil salinities. This designation, however, has been retained for Olema Marsh and portions of White House Pool park, neither of which has been farmed in recent decades or currently has any realistic potential for farming. Farmland of Local Importance in the Project Area represents less than 0.2 percent of this mapped type in Marin County.

Grazing Land is defined in Government Code §65570(b)(3) as: "...land on which the existing vegetation, whether grown naturally or through management, is suitable for grazing or browsing of livestock" (California Department of Conservation 2006). The minimum mapping unit for Grazing Land is 40 acres. Grazing Land does not include land that is heavily brushed, timbered, excessively steep or rocky lands which restrict the access and movement of livestock. The FMMP convenes a grazing land advisory committee in each project county to help identify grazing lands. The committees consist of members of the local livestock ranching community, livestock ranching organizations, and the U. C. Cooperative Extension livestock advisor. The FMMP works with the president of the local Cattlemen's Association and the U.C. Cooperative Extension livestock advisor in selecting members of these committees. As noted earlier, Grazing Land is a new designation within the Project Area, with most of these lands being Farmland of Statewide or Local Importance that were reclassified. Grazing Land in the Project Area represents less than 0.3 percent of this farmland type in Marin County.

As discussed under Land Use, both the FPPA and CEQA require that projects that might affect prime, unique, and important farmland soil types complete a Land Evaluation and Site Assessment (LESA). LESA establishes a farmland conversion impact rating score that can be used as an indicator to determine the magnitude of adverse impacts on farmland. Results of the LESA are discussed under Land Use and Planning subsection in Chapter 4.

Soil Resource Issues - Sediment Quality and Contamination

One of the most valuable functions that wetlands can contribute to improving the health of a watershed is filtration and/or transformation of nutrients, sediment and contaminants in associated surface and ground water sources. Soluble and sediment-bound nutrients, sediment, bacteria, and contaminants, such as metals, pesticides, and polyalkylated hydrocarbons, can enter wetlands through tidal or freshwater flow. Once they have entered a wetland, sediments and nutrients are deposited onto the floodplain, with nutrients often transformed within the soil or uptaken by plants. Contaminants are often precipitated and bound through sediment reduction processes into insoluble iron or sulfide compounds, dissolved organic compounds, or humic acids (Gambrell 1994; Horne 2000). Natural wetlands are believed to remove as much as 50 percent of ammonium and Total Nitrogen, 20 percent of Total Phosphates, and 30 percent of metals from source waters (Kadlec and Knight 1996).

With the increasing number of wetland restoration projects in San Francisco Bay and the central California coast in the past decade, concerns have been raised among biologists and hydrologists that these stable “sinks” for contaminants could potentially become “sources” of contamination to the environment (Davis et al. 2003). This remobilization could potentially reduce productivity and filtering functions of wetlands, create water quality problems, or reintroduce toxins that may be uptaken by wildlife (Davis et al. 2003).

Wetland restoration can affect reintroduction of nutrients, sediment, and contaminants to the environment in several ways. First, removal of levees in diked marshes could cause sediment erosion through tidal overwash or development of new channels, thereby potentially resuspending sediment and nutrient- and contaminant-laden sediments. Secondly, changes in the hydrologic regime of areas undergoing restoration also can increase the potential for remobilization of nutrients and contaminants. Many contaminants become more soluble under conditions of low pH that sometimes result when reduced sediments become oxidized, such as when tidal action is introduced to diked areas that were consistently inundated or impounded previously (DeLaune and Smith 1985; Soukup and Portnoy 1986; Gambrell et al. 1991; Peverly and Kopka 1991; Satawathananont et al. 1991; Gambrell 1994; Anisfeld and Benoit 1997). This oxidation can cause a flush of nutrients within overlying waters from breakdown of undecomposed organic matter within formerly anoxic soils (Soukup and Portnoy 1986, Anisfeld and Benoit 1997).

The Tomales Bay watershed is generally considered pristine relative to other large watersheds along the California coast. However, as will be discussed in greater detail under Hydrologic Resources – Water Quality, it is not immune to the negative effects of anthropogenic influences, such as logging, agriculture, leaking septic systems, oil spills, and mercury mining. The absence of large scale industry and the relatively low density of people and cars within the watershed have limited the potential for direct discharge of contaminants such as polychlorinated biphenyls (PCBs) and hydrocarbons, yet there is still the possibility of indirect contamination to Tomales Bay via atmospheric deposition of PCBs and hydrocarbons originating from outside the watershed (Parsons and Allen 2004a). The prevalence of dairy and beef cattle ranching, as well as other forms of agriculture, in this watershed increases the potential for the presence of herbicides and pesticides and other types of pollutants such as bacteria and excessive nutrients relative to more contaminants generally associated with more urban environments such as PCBs (Parsons and Allen 2004a).

Because restoration activities are anticipated to cause some degree of soil disturbance and relocation that might cause any potential nutrients or contaminants present to be released, the Park Service conducted screening-level sediment contaminant and nutrient studies in the Giacomini Ranch and adjacent areas in 2003 and 2005 (Parsons and Allen 2004a, NPS, unpub. data). More information on nutrients and pathogen levels within Project Area waters can be found under the Water Resources – Water Quality discussion.

Regulatory and Policy Setting

From a regulatory perspective, the issue of sediment contamination is tightly linked to water quality. The San Francisco Regional Water Quality Control Board (RWQCB) has established narrative objectives for the amount of suspended sediment in waters, and suspended sediment often is bound to nutrients, pathogens, and contaminants such as mercury. Indeed, the tight link between mercury and sediment transport, deposition, and resuspension has led the RWQCB to be the lead agency evaluating the effect of mercury from the Gambonini Mine on Walker Creek and Tomales Bay under the Clean Water Act, as well as under other state legislation. The Clean Water Act is discussed under Water Resources – Water Quality. The Basin Plan (Regional Water Quality Control Board (RWQCB) 1995a)notes that the suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses. In addition, “controllable water quality factors shall not cause a detrimental increase in the concentrations of toxic pollutants in sediments or aquatic life” (RWQCB 1995a).

The explosion in chemical manufacturing and marketing during the mid 20^{th} century dramatically increased the threat to public health from contamination. During the last 50 years, hundreds of thousands of chemicals have been developed, and the production of synthetic chemicals jumped from 1.3 billion lbs. in 1940 to 320 billion lbs. in 1980 (Orford 1991). Serious public health issues associated with dumping or storage of very hazardous chemicals such as the infamous Love Canal prompted a series of federal pieces of legislation designed to regulate transport and disposal of hazardous waste and require clean-up of toxic areas through the Resource Conservation and Recovery Act (42 U.S.C. 6901 et seq. --1976) and Comprehensive Environmental Response, Compensation, and Liability Act (42 (U.S.C. 9601 et seq. -- 1980), also known as Superfund.

Nutrients

Relative to some other natural vegetation communities, most tidal marshes would be considered nutrient-poor, at least in terms of nitrogen (Mitsch and Gosselink 1993). While the pastures have remained largely wetland in nature despite diking, nutrient concentrations appear to exceed those of natural, undiked marshes, although spot sampling was only conducted once in August 2005 (NPS, unpub. data). Nitrate levels in some of the East Pasture surface soils ranged between 6 – 29 mg/L, while phosphorus ranged between 7-11 mg/L (n=3; NPS, unpub. data). In comparison, nitrate in the undiked marsh north of Giacomini Ranch ranged between 3-6 mg/L, and phosphorous ranged between 5-8 mg/L (n=2; NPS, unpub. data). Interestingly, nitrates in the West Pasture freshwater marsh, which is only infrequently grazed by cattle, ranged as high as from 29-81 mg/L, while phosphorous concentrations were very low, ranging from 1-3 mg/L (n=2, NPS, unpub. data). Nitrate data for the freshwater marsh may reflect more nitrogen potential of the soil: drying of soils for analysis may have increased organic matter breakdown and nitrification of ammonia to nitrates, which is normally precluded in soils with prolonged waterlogging and anoxia. Not surprisingly, the highest nitrate and phosphorous concentrations were recorded in the East Pasture field used for manure disposal, with concentrations in surface soils of nitrates reaching 134 mg/L and phosphorous, 489 mg/L (NPS, unpub. data). In the manure field, nitrate concentrations dropped by half 6 inches below the soil surface, but phosphorous concentrations remained more variable (NPS, unpub. data).

Metals and Other Contaminants

Many watersheds along the central California coast are naturally high in certain metals such as mercury and nickel due to the presence of mineral deposits and ultramafic rocks. Mercury used to extract gold during the gold rush period in the Sierra Nevada Mountains came from the coastal ranges in California. Later, mercury was mined for other purposes. Between 1964 and 1970, the Gambonini family operated a cinnabar ore or mercury sulfide mine in the Walker Creek watershed, a sub-watershed of Tomales Bay (Whyte and Kirchner 2000; TBWC 2002). Waste from this mine was stored in a tailings pond that breached during extreme storm events in 1982, sending much of this mercury-laden sediment downstream to Tomales Bay. As much as 180 lbs of mercury moved downstream over a period of two months (D. Whyte, RWQCB, pers. comm. in Parsons and Allen 2004a). Whyte and Ganguli (2000) conducted sediment sampling throughout Tomales Bay in the 1990s and determined that mercury concentrations were highest at the mouth of Walker Creek, averaging 10-12 ppm, and decreased in a bell-curve fashion with distance from the mouth. Through sulfur reduction processes in the sediment, this mercury can become methylated and made available to benthic organisms such as oysters and ghost shrimp. These invertebrates, in turn, are consumed by organisms of higher trophic order such as fish and birds.

Studies in Tomales Bay have shown that mercury concentrations in the tissues of sharks, halibut, perch and bat rays from Tomales Bay are slightly higher than those from San Francisco Bay (D. Whyte, RWQCB, pers. comm. in Parsons and Allen 2004a). In addition, mercury levels in liver tissue of ducks from Tomales Bay were two to three times greater than those of ducks from historically contaminated Suisun Bay. Whyte noted that most of the current effects of mercury contamination in Tomales Bay result from resuspension of mercury-laden sediments that were deposited during or slightly after the 1982 storm events. Sediment resuspension of this nature occurs because of scouring and channel migration related to tidal flow (D. Whyte, RWQCB, pers. comm. in Parsons and Allen 2004a).

Results from a study conducted by Long et al. (1990) support the growing awareness that Tomales Bay is not as pristine as previously assumed. The study subjected various benthic invertebrates to survival tests in sediment samples collected from sites in Tomales Bay and San Francisco Bay. Chemical analyses of the Tomales Bay sediment suggested that it was not contaminated, yet the Tomales Bay sediment bioassay samples were categorized with samples from Oakland Inner Harbor as among the most toxic to the test organisms. The same study found that benthos samples collected from Tomales Bay were dominated by relatively hardy polychaetes and molluscs and were nearly devoid of sensitive crustaceans. Based on these finding, the authors concluded that some unknown factor or factors had rendered Tomales Bay sediments "relatively inhospitable" to many benthic organisms.

On the Giacomini Ranch, ranching activities appear to have resulted in comparatively little contamination of soils (Parsons and Allen 2004a). Based on land use and land management practices, the potential for toxic contaminants within the ranch itself would seem to be restricted to decades of hunting with lead shot in portions of the East Pasture and possible spraying of undesirable plants and pests with herbicides or pesticides (Parsons and Allen 2004a). However, the Project Area may be affected by outside sources of contaminants such as mercury from the Gambonini mine and pollutants from nearby landfills. Several RWQCB sampling events between 1999 and 2000 documented the presence of leachates, if not organic compounds and other types of contaminants, in surface waters of Tomasini Creek near Mesa Road one mile downstream from the now closed West Marin Landfill, which at one point took both hazardous and household wastes (D. Elias, Engineering Geologist, RWQCB, *pers. comm.*). Another dump may have once existed just south of the Giacomini Ranch adjacent to Lagunitas Creek and the Green Bridge that served the town of Point Reyes Station during the 1920s -1930s. While perhaps not used for dumping of higher volumes of toxic wastes as would be older landfills in urban and industrial areas, these landfills still represent sources of possible contamination to the Project Area, particularly these landfills were constructed and largely operated during a period of less stringent regulation regarding liners, distance to groundwater tables, etc.

In the Seashore's study (Parsons and Allen 2004a), the only contaminant that exceeded National Oceanic and Atmospheric Administration's (NOAA's) sediment quality guidelines was nickel, which exceeded NOAA's Effects Range-Median (ERM) at several of the 20 sampling locations. NOAA's ERM is national benchmark that correlates to the concentration at which adverse benthic impacts are found in approximately 50 percent of studies, while Effects-Range Low (ERL) represents a concentration at which adverse impacts were detected in 10 percent of the studies. Nickel and some other metals are naturally high in certain geologic formations, including the Franciscan Formation, which borders the Project Area to the east. Cadmium was also detected at concentrations exceeding the Ambient Sediment Concentration (ASC) standards for San Francisco Bay in Tomasini Creek near Mesa Road, but the level was still substantially lower than NOAA's ERL or ERM standards (Parsons and Allen 2004a).

The two analytes that perhaps were of most concern – methylated mercury and lead – due to watershed mercury contamination and long-term hunting in the Project Area occurred at concentrations well below both published standards and levels observed in San Francisco Bay subtidal and wetland areas (Parsons and Allen 2004a). Reporting limits for selenium and organics laboratory analytical methodologies used were high enough that they precluded comparisons with published standards (Parsons and Allen 2004a). The relatively rural, non-industrialized nature of this watershed suggests, however, the potential for selenium and organics contamination is relatively low, except for those contaminants that disperse through atmospheric deposition, as well as point source and non-point discharge from isolated features such as the West Marin Landfill (Parsons and Allen 2004a).

Soil Resources and Wetland Functionality

As described earlier, soils are integral components of many hydrologic and ecological functions, either directly or indirectly. These functions include water quality improvement, carbon export, and wildlife habitat use and support. The ability of soils to bind or retain contaminants and thereby improve water quality is strongly related to texture (e.g., percentage of clays, silts, sands, and other material), organic matter (e.g., decomposing plant matter), and oxygen. With the exception of deltas, most natural tidal and freshwater marshes have high amounts of fine sediments such as clay and organic matter that, because of their chemical properties, act to strongly bind contaminants. Materials such as sands and gravels are not only more porous or contain more air space between soil particles, but do not possess the same chemical properties that enable nutrients, metals, pathogens, and other contaminants to bind strongly to them. Another important parameter of wetland soils is the lack of oxygen. Sustained inundation or saturation of soils by water causes the soil environment to become reduced or anaerobic, which initiates a complex biogeochemical that helps to lock contaminants into the soils. Once bound to soils, these contaminants are rarely released back into their environment, unless there are drastic changes in wetland conditions such as oxidation of soils due to dewatering. The natural filtering mechanisms of wetland soils have encouraged many municipalities to turn to treatment wetlands to treat or, polish wastewater.

Because of its unique geologic history, soils within the Giacomini Ranch contain less clay and peat material than many other historic marshes. In the East Pasture, very fine, estuarine-derived clays interbedded with peats – very fine decomposed organic matter -- were typically overlain by anywhere from 1.5- to 5 feet of clayey to sandy alluvial material derived from fluvial or creek sources (KHE 2006a). Organic content of the estuarine clays appears relatively low based on laboratory analyses, ranging from 5- to 18- percent (KHE 2006a) compared to 20- to 40 percent in many natural marshes. Soils in the West Pasture consist of an interbedded mixture of layers of gravel, sand, silt, and clay, with the clays again varying in the amount of organic matter content (KHE 2006a). Conversely, Olema Marsh is dominated by peat and fine-grained clays, with substantially lower amounts of fluvial-derived sand, clay, and silt particles (KHE 2006a).

Most of the overlying soils in the Giacomini Ranch undoubtedly date to the massive influx of sedimentation from the upstream watershed that started in the 1860s and still continues to some extent to this day, although the levees have substantially reduced the amount of deposition on the historic floodplains of Lagunitas and Tomasini Creeks. In addition, alluvial material has deposited at the mouths of many of the small creeks and drainages within the Project Area. To a lesser degree, agricultural management has resulted in selective filling of pastures, particularly in the south end of the East Pasture. In contrast, land management in the Bear Valley Creek watershed appears to have somehow precluded downstream deposition of alluvium – which is also prevalent in this system -- into Olema Marsh, preserving a vegetation-controlled depositional environment. The fine-grained clays occurring with the abundant peat were probably deposited when conditions were estuarine (KHE 2006a)

Air Resources

Air Resource Issues - Air Quality

Regulatory and Policy Setting

Under NPS-77 (Natural Resource Management Guidelines), the Park Service is directed to "seek to perpetuate the best possible air quality in parks because of its critical importance to visitor enjoyment, human health, scenic vistas, and the preservation of natural systems and cultural resources." Parks are urged to "assume an aggressive role in promoting and pursuing measures to safeguard [air quality related values] from the adverse impacts of air pollution." As a federal agency, the Park Service must comply with the Clean Air Act of 1970 (CAA), which underwent several major revisions in 1977 and 1990. Under the CAA, the Seashore is classified as a mandatory Class I area. Title I of the CAA amendments of 1990 defines Class I areas as including all national parks greater than 6,000 acres that were in existence when the CAA was amended in 1977 and identifies these areas as receiving the most stringent protection from air pollution damage. The Park Service is responsible for the protection of parks from ambient air quality impacts, including air quality-related values (AQRVs) such as visibility and the protection of plants, animals, soils, water quality, cultural and historic structures from the effects of contaminants. The northern lands of the GGNRA, including the Project Area, are a federal Class II area.

The CAA charges the Environmental Protection Agency (EPA) with identifying national ambient air quality standards to protect public health and welfare. Standards have been set for seven pollutants: ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter less than 10 microns (PM_{10}), very fine particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), and lead (Pb). A description of these pollutants can be found below and in Table 4. Ozone is produced by the combination of pollutants from many sources, including smokestacks, cars, paints and solvents and is one of the chemicals responsible for formation of smog. Carbon monoxide is a colorless, odorless, poisonous gas that is produced by incomplete burning of carbon-based fuels, including gasoline, oil and wood. Nitrogen dioxide, produced by combustion sources such as cars, power plants, and industrial engines, is a respiratory irritant and a precursor to ozone and, therefore, smog formation. Sulfur dioxide is a gas produced by burning coal, most notably in power plants, and plays an important role in the production of acid rain. Reactive Organic Gas (ROG), a reactive chemical gas composed of hydrocarbons, may contribute to the formation of smog. Particulates are produced by soots, dusts, and smokes and are also a respiratory irritant. If a standard for a particular pollutant is exceeded more than three times in three years in an air basin, it is considered a non-attainment area and is then subject to more stringent planning and pollution control requirements. The San Francisco Bay Area Air Basin, under which the Project Area falls, is a federal non-attainment area for ozone (Table 5).

The federal government has ceded responsibility and authority to establish air quality standards and regulations to states. Section 176 of the Act or the conformity rule requires federal actions to conform to state implementation plans for achieving and maintaining the air quality standards. Federal actions cannot cause or contribute to new violations, increase the frequency or severity of any existing violation, interfere with timely attainment or maintenance of a standard, delay emission reduction milestones, or contradict the State Implementation Plan. Therefore, all Park Service areas are required to comply with state laws on these matters regardless of the type of legal jurisdiction that applies to other activities within the Park Service unit.

TABLE 4. OVERVIEW OF POLLUTANTS OF GREATEST CONCERN IN THE SFBAAB

Pollutant	Sources	Health and Other Concerns
Ozone	Formed by a photochemical reaction in the atmosphere; ozone precursors, including reactive organic gases and oxides of nitrogen (NOx), react in the atmosphere in the presence of sunlight to form ozone. Ozone precursors are emitted by mobile sources such as vehicles, and by stationary combustion equipment.	A severe eye, nose, and throat irritant; increases susceptibility to respiratory infections. An oxidant; can cause substantial damage to synthetic rubber, textiles, and other materials. Produces leaf discoloration and cell damage in plants.
PM10	Results from many kinds of dust- and fume-producing activities, such as demolition, construction, and vehicular traffic; entrained road dust from motor vehicles accounts for approximately two-thirds of the regional PM10 inventory in the project area.	Health concerns focus on particles small enough to be drawn into the lungs when inhaled (PM10). Can increase the risk of chronic respiratory disease with extended exposure.
CO	Motor vehicles are the primary source of CO emissions in most areas. In the urbanized portions of the San Francisco Bay Area, high CO levels primarily develop during the winter near congested intersections, when periods of light winds combine with the formation of ground-level temperature inversions from evening through early morning. In addition, motor vehicles exhibit increased CO emission rates at low air temperatures.	Combines readily with hemoglobin and thus reduces the amount of oxygen transported in the bloodstream. Effects on humans range from slight headaches to nausea to death.

Prior to even initial federal efforts to regulate air quality, the state of California was already establishing air quality standards and necessary controls for mobile vehicle emissions through the state Department of Public Health in the late 1950s. In 1988, the California Clean Air Act was passed. California differs from every other state in that it has retained the authority to develop its own vehicle emissions standards if those standards are at least as stringent as the federal standards under Section 209(b) of the CAA.

The California Air Resources Board (CARB) sets air quality standards for the state targeted at reducing emissions in each of the 35 local air districts. Both CARB and the USEPA have general oversight responsibilities for the purpose of making sure local rules and regulations and stationary source permits issued are consistent towards attainment and maintenance of the California and National Ambient Air Quality Standards (AAQS). To protect public health and welfare, the California Air Resources Board (CARB) has set stricter ambient air quality standards than national standards (Table 5). Under the 1988 California Clean Air Act, air basins were designated as attainment, non-attainment, or unclassified for the state standards. The Bay Area Air Basin, one of the 35 local air districts, is classified as a California non-attainment area for ozone and particulate matter (Table 5). The Bay Area Air Quality Management District (BAAQMD) is the air quality management district for the Project Area and has primary responsibility for control of air pollution. The County of Marin has also established policies regarding air quality in the Marin CWP (Marin County Community Development Agency 2005). The local general plan for the appropriate city or county must be consistent with the Clean Air Plan for this guideline to apply (BAAQMD 1999). The Marin CWP is considered consistent with the Clean Air Plan (Illingworth & Rodkin and Nichols Berman 2002).

TABLE 5. AMBIENT AIR QUALITY STANDARDS & BAY AREA ATTAINMENT STATUS

Pollutant	Averaging Time	California Standards[1]		National Standards[2]	
		Concentration	Attainment Status	Concentration[3]	Attainment Status
Ozone (O_3)	8 Hour	0.070 ppm (137µg/m)	U	0.08 ppm	N
	1 Hour	0.09 ppm (180 µg/m)	N		
Carbon Monoxide (CO)	8 Hour	9.0 ppm (10 mg/m)	A	9 ppm (10 mg/m)	A
	1 Hour	20 ppm (23 mg/m)	A	35 ppm (40 mg/m)	A
Nitrogen Dioxide (NO_2)	Annual Average			0.053 ppm (100 µg/m)	A
	1 Hour	0.25 ppm (470 µg/m)	A		
Sulfur Dioxide (SO2)	Annual Average			0.03 ppm (80 µg/m)	A
	24 Hour	0.04 ppm (105 µg/m)	A	0.14 ppm (365 µg/m)	A
	1 Hour	0.25 ppm (655 µg/m)	A		
Particulate Matter (PM10)	Annual Arithmetic Mean	20 µg/m	N	50 µg/m	A
	24 Hour	50 µg/m	N	150 µg/m	U
Particulate Matter Fine (PM2.5)	Annual Arithmetic Mean	12 µg/m	N	15 µg/m	A
	24 Hour			65 µg/m	A
Sulfates	24 Hour	25 µg/m	A		
Lead (Pb)	Calendar Quarter			1.5 µg/m	A
	30 Day Average	1.5 µg/m	A		
Hydrogen Sulfide	1 Hour	0.03 ppm (42 µg/m)	U		
Vinyl Chloride (chloroethene)	24 Hour	0.010 ppm (26 µg/m)	No information available		
Visibility Reducing particles	8 Hour (1000 to 1800 PST)	(See note 3)	A		
A = Attainment N = Nonattainment U = Unclassified					
mg/m^3=milligrams per cubic meter		ppm=parts per million		µg/m^3=micrograms per cubic meter	

1. California standards for ozone, carbon monoxide (except Lake Tahoe), sulfur dioxide (1-hour and 24-hour), nitrogen dioxide, suspended particulate matter - PM10, and visibility reducing particles are values that are not to be exceeded. The standards for sulfates, Lake Tahoe carbon monoxide, lead, hydrogen sulfide, and vinyl chloride are not to be equaled or exceeded. If the standard is for a 1-hour, 8-hour or 24-hour average (i.e., all standards except for lead and the PM10 annual standard), some measurements may be excluded. Measurements may be excluded that would occur less than once per year on the average.
2. National standards other than for ozone, particulates and those based on annual averages are not to be exceeded more than once a year. The 1-hour ozone standard is attained if, during the most recent three-year period, the average number of days per year with maximum hourly concentrations above the standard is equal to or less than one. The 8-hour ozone standard is attained when the 3-year average of the 4th highest daily concentrations is 0.08 ppm or less. The 24-hour PM10 standard is attained when the 3-year average of the 99th percentile of monitored concentrations is less than 150 µg/m^3. The 24-hour PM2.5 standard is attained when the 3-year average of 98th percentiles is less than 65 µg/m^3. Except for the national particulate standards, annual standards are met if the annual average falls below the standard at every site. The national annual particulate standard for PM10 is met if the 3-year average falls below the standard at every site. The annual PM2.5 standard is met if the 3-year average of annual averages spatially-averaged across officially designed clusters of sites falls below the standard.
3. Statewide VRP Standard (except Lake Tahoe Air Basin): Particles in sufficient amount to produce an extinction coefficient of 0.23 per kilometer when the relative humidity is less than 70 percent. This standard is intended to limit the frequency and severity of visibility impairment due to regional haze and is equivalent to a 10-mile nominal visual range.

Air Quality Resources within the Region

A cooperative program, the Interagency Monitoring of Protected Visual Environments (IMPROVE), between the EPA, federal land managers, and state air agencies, was formed to monitor visibility in Class I areas. Data published in a recent IMPROVE report shows that visibility at the Seashore improved during the period of 1996 to 1999 primarily due to a decrease in nitrate particulates, a major component of visibility-blocking material in coastal California. Particulate nitrate is formed from nitrogen oxide and hydrocarbon gases emitted into the atmosphere from fires, diesel engines, and other sources (Malm 2000). Monitoring by the Park Service found no ozone exceedences at the Seashore under either the California or federal standard. Park air resources are rated as having low exposure to ozone, sulfur, and nitrogen emissions and low potential for acidification of surface waters. A recent Park Service report states that “there are no significant air pollution effect concerns in this park [the Seashore] at the present time” (Sullivan et al. 2001).

Some of the greatest threats to air quality within the Seashore and the western portions of Marin County come from outside the region. In 2000, Marin County had a total population of 247,289 (U.S. Census Bureau 2000). As discussed earlier, most of Marin’s population lives to the south and east of the Project Area along the county’s main transportation corridor, Highway 101. Other populated areas -- including Petaluma in Sonoma County -- are located in a more easterly direction, inland from Point Reyes. Only a small, relatively scattered population lives in the vicinity of the Seashore. Air quality within the coastal portion of rural West Marin can be affected by problems outside the immediate vicinity of the Seashore. In general, the BAAQMD has been unable to attain the ozone (O3) and carbon monoxide (CO; pertinent to urbanized areas only) standards set by the AAQS for the Bay Area. These air quality problems have the potential to affect seemingly unpolluted coastal regions because of wind, air temperature, gradients, and local and regional topography.

Some of the greatest threats to air quality within the Seashore and the western portions of Marin County come from outside the region.

The marine influence that moderates temperatures along the central California coast also affects wind direction and speed. Many areas of the Seashore, particularly along the Drakes Bay, the Lighthouse, and Point Reyes Headlands, are exceptionally windy. Wind speed along the west Marin Coast averages 8- to 10 mph (BAAQMD 2003). During the winter, the predominant regional surface winds flow from the north-northeast (Bell 1958). During spring and summer, stronger north-northwest winds dominate (Bell 1958). These northwesterly winds are primarily caused by the combination of high pressure offshore and the warmer air inland. These winds blow off the ocean and are slowed down, if not intercepted completely, by the complex terrain of the Bolinas Ridge (BAAQMD 2003). During the fall transition, warm easterly winds from the hot, dry inland areas often break through to the coast.

Bolinas Ridge provides a topographic barrier for air pollutants from San Francisco Bay, as since winds play a major role in dispersing pollutants far from respective sources. Air pollution in the region is moderated by strong, westerly winds most of the year. Other sources of pollutants are inversions. When cold air becomes trapped under warm air, the air masses cannot mix, and pollutants begin to accumulate. The frequent occurrence of temperature inversions over the Seashore could concentrate air pollution levels near the ground. Pollutants are more concentrated near the ground during colder weather or after sunset. In general, “the influence of the marine air keeps the pollution levels low” (BAAQMD 2003).

Sensitive receptors refer to land uses that are considered particularly sensitive to decreases in air quality. The designation typically refers to uses such as residences, schools, libraries, hospitals, and other similar facilities where there are large concentrations of children and young people; the elderly; and/or the chronically ill. Because the Project Area is within a relatively rural community, there are not a large number of sensitive receptors located nearby. However, there are small schools, preschools, and a library in the town of Point Reyes Station. In addition, because the Project Area occurs in an area is widely used for recreation, wildlife viewing, agricultural production, and scientific research, and these uses are potentially vulnerable to air quality degradation.

The only air pollutant currently measured in the Point Reyes region is PM2.5 or small particulate aerosols that affect acid deposition and regional haze. Recent data (1999-2001) indicate a daily average concentration of 8.330 ug/m3 or less averaged over three years of data collection, which is well below the state and federal AAQSs of 12 and 15 ug/m3, respectively. As no other ambient air pollutant is measured in this region, air quality data were obtained from other nearby BAAQMD monitoring stations in San Rafael (Marin), Santa Rosa (Sonoma), and Vallejo (Napa). In summary, these stations, which are located in more heavily developed areas, met standards for carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and federal, but not state, standards for ambient particulates smaller than 10 microns (BAAQMD 2003). Santa Rosa exceeded the state's maximum 24-hour average for ozone twice during the three-year period and California's one-hour ozone standard once (BAAQMD 2003b).

Air Resource Issues – Noise and Soundscapes

Background and Regulatory and Policy Setting

While noise often has a negative connotation, one of the intrinsic values of national parks remains the potential for hearing "natural" noises such as crashing waves, running streams, thunder, or singing birds. A combination of noises that is intrinsic to a natural landscape is often characterized as a soundscape. The ability to hear these natural noises in a soundscape is somewhat dependent on the absence of unwanted sound such as urban noise. Unwanted sound can be simply intrusive, destroying either a relaxing experience or the comfort of one's home, or harmful to people's health through hearing impairment or loss.

Unlike more urban parks, the Seashore and north district of GGNRA are located in a rural portion of western Marin County and must contend less with the intrusive influences of urbanization than the southern portions of GGNRA. Regardless of location, however, the Park Service is directed to preserve, to the greatest extent possible, the natural soundscapes of parks and to protect natural soundscapes from degradation due to noise, defined as "undesirable human-caused sound" (NPS 2001, Section 4.9). The natural soundscape is defined as the aggregate of all the natural sounds that occur in parks, absent human-caused sound, together with the physical capacity of transmitting natural sounds (NPS 2001, Section 4.9). The Park Service policy is a more stringent standard than set by the federal Noise Control Act of 1972 or most general plans produced by cities or counties.

The federal Noise Control Act required federal agencies to promote an environment free of the noise that can jeopardize public health or welfare. Sound can be characterized using two parameters: amplitude (loudness) and frequency (tone). The agency tasked with implementing the Noise Control Act, the EPA, established outdoor limits of 55 decibels (dB) and indoor limits of 45 dB averaged throughout a 24-hour period. Decibels refer to the amplitude or peak pressure of the sound wave and are interpreted by humans and wildlife as different degrees of sound loudness. For comparison purposes, an average office has mean noise levels of 60 dB, while close proximity to a jet engine has noise levels as high as 140 dB (Egan 1972; HUD 2004). The noise level of rustling leaves in a forest -- the sound that many visitors come to parks to experience – can be as low as 20 dB (Egan 1972 *in* HUD 2004). Laboratory measurements have correlated a 10 dB increase in amplitude with a perceived doubling of loudness and a 3 dB change in amplitude as the minimum audible difference perceptible to the average person (Federal Highway Administration 1982; EDAW Inc. 2001).

In 1994, the Marin County Noise Element mandated that residences, public spaces, and institutions not be subjected to noise levels above an average of 60 dB over a 24-hour period. Many planning agencies use a 24-hour average of noise intensity, with a 10 dB "penalty" added for nighttime noise (10:00 p.m. to 7:00 a.m.) to account for the greater intrusiveness of loud noises during this time of the day (California Code of Regulations 1988). Marin County is currently in the process of revamping the CWP with the last draft issued in 2005. The County has also developed noise criteria for significance thresholds in its Marin County Environmental Impact Review Guidelines (Marin County Community Development Agency 1994). These criteria generally characterize noise impacts as significant if the project would generate noise that conflicts with countywide or state noise standards; 2) substantially increases noise levels in areas of sensitive receptors; or 3) is not compatible with baseline noise levels.

Noise and Soundscape Resources within the Project Area

Major noise producers in most areas include highway traffic, trains, planes, boats, and industry-related machinery within industrial zones. In rural areas such as west Marin, major producers of undesirable human-caused sound are limited to automobile and truck traffic, jet airplanes, individual businesses, agricultural ranch activities, and individual construction projects. In general, ambient noise levels remain lower in rural areas than in urban areas. In urban areas, ambient noise levels typically range from approximately 60 to 70 dBA, whereas, in rural areas, ambient noise levels range from 40 to 50 dBA. No ambient noise levels are available for the Seashore. However, Marin County assessed noise levels on State Route 1 south of Point Reyes Station in 1987 and 2001, and average ambient noise levels over a 24-hour period climbed from 62 to 65 decibels during those 14 years (Marin County Community Development Agency 2004)). Another ambient noise survey conducted as part of the Affordable Housing project in Point Reyes Station recorded 24-hour average ambient noise levels of 69 dBA at State Route 1 and a newly constructed street near Mesa Road, Williams Street, with maximum and minimum levels of 87 and 43 dBA, respectively. Average ambient noise levels of 66 dBA were measured at Mesa Road and Commodore Webster Drive, with maximum and minimum levels of 87 and 45 dBA, respectively (EDAW Inc. 2001). Traffic on local roads and State Route 1 constituted the dominant noise source during this 2000 survey, which was conducted in the late afternoon (EDAW Inc. 2001).

On its eastern boundary, the Project Area is located directly adjacent to Point Reyes Station, where automobile and truck traffic, agricultural ranch activities, and individual businesses in the town constitute most of the anthropogenic noise sources. On its western boundary, the Project Area is located next to Inverness Park, a small residential community with more limited ranch and business activity than Point Reyes Station. However, Sir Francis Drake Boulevard, the main road for visitors, residents, and park staff traveling to the interior of the Seashore, runs through Inverness Park, and this road generates more than 300,000 vehicle trips per year (NPS 2002). Most of the homes in Inverness Park and all of those in the town of Point Reyes Station proper are located above the Project Area either on Inverness Ridge slope or the top of the Point Reyes Mesa, respectively. There are approximately 20-25 homes that are at the same elevation or just slightly higher than the Project Area in Inverness Park along Sir Francis Drake Boulevard and along Levee Road near Point Reyes Station. The topography of the Project Area has some effect on noise and soundscape resources, with noise generated by or near the roadways and pastures generally carried upwards towards residences on the Inverness Ridge or Point Reyes Mesa.

Water Resources – Hydraulics and Hydrologic Processes

The complex geologic setting of coastal Marin has resulted in an equally complex and diverse hydrologic setting, characterized by tides, creeks with seasonal and perennial water flow, and abundant groundwater that either remains belowground as aquifers or emerges at the ground surface as seeps and springs. The transition from precipitation- and groundwater-derived freshwater at the headwaters to the tidally dominated outer portion of Tomales Bay and the Pacific Ocean beyond superimposes another layer of complexity defined by salinity, with the inner portions of Tomales Bay representing the brackish interface between marine and freshwater influences. The Project Area represents the largest transitional zones between marine and freshwater influences within the watershed.

The movement of water and sediment through the watershed, from Inverness and Bolinas Ridges to Tomales Bay, relies upon a complex interaction between hydrologic, hydraulic, sediment transport, and geomorphic processes, including precipitation, fog drip, run-off; infiltration; evaporation; flooding; connectivity of the stream with the floodplain; sediment transport; surface water interaction with the groundwater table; lateral creek migration, scour and deposition, etc. For the purposes of this document, all of these processes are collectively referred to as “hydrologic processes.”

The purpose of the project is to restore tidal and freshwater hydrologic processes within the Project Area. Being at the head of the Tomales Bay estuary, both tidal and freshwater hydrologic processes are important to the Project Area and are the cornerstone for almost of the other functions provided by wetland ecosystems. These processes not only result in important hydrologic functions such as floodwater retention, groundwater recharge, and water quality improvement, but are integral to ecological functions (e.g., carbon export and wildlife habitat) and economic services (e.g., recreation and industries such as oyster-growing and fisheries). Realizing the importance of natural hydrologic processes to wetland function, the Park Service and CSLC focused on removing impediments to tides and creeks as the project's primary goal.

Regulatory and Policy Setting

While water quality and impacts to wetlands are highly regulated, hydrologic processes have received less regulatory attention. In recent decades, more local, state, and federal agencies have adopted policies regarding hydrologic processes.

The 2001 National Park Service Management Policies, support practices that "re-establish natural functions and processes in human-disturbed components of natural systems in parks unless otherwise directed by Congress…..Impacts to natural systems resulting from human disturbances include ……changes to hydrologic patterns and sediment transport; the acceleration of erosion and sedimentation; and the disruption of natural processes. The Service will seek to return human-disturbed areas to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated"(NPS 2001a, Section 4.1.5). The 2001 Management Policies also call for parks to "protect, preserve, and restore the natural resources and functions of floodplains (NPS 2001a, Section 4.6.4)," which includes benefits such as floodwater storage.

Marin County also promotes restoration and enhancement of watersheds and natural stream channel function (including protection and enhancement of fish habitat) in its draft update of the Countywide Plan (2005). In the Coastal Zone, the LCP (Marin County Comprehensive Planning Department 1981) also includes policies regarding stream alterations, including protection of stream channels from impoundments, diversions, channelizations, or other substantial alterations, as well as protection of at least 100 feet on either side of creeks as "buffers" to increase wildlife habitat quality and water quality benefits. The Point Reyes Station Community Plan (Marin County Community Planning Department 2000) further supports preservation of streams and streamside environments in their natural conditions, including protection of existing riparian habitat or "buffers" and removal of invasive plant species, and protection of Lagunitas Creek, specifically its water quality, coho salmon and steelhead populations, and other aquatic life in its policies.

Water Resources – Tidal and Freshwater Flows

The Project Area represents a mixture of tidal, freshwater creek or fluvial, and groundwater hydrologic sources (Figure 27). The zone of influence for each of these hydrologic influences shows considerable overlap within the Project Area, making it a very hydrologically dynamic and complex system. A more detailed description of each of these sources follows below.

As described earlier, the functionality of wetlands is integrally tied to the presence of hydrologic sources such as tides, fluvial or creek flow, and groundwater. The importance of hydrology not only relates to it being a source of water for wetlands, but to its properties and the work accomplished by water when it moves either through bi-directional flow of tides or the uni-directional flow of creeks and groundwater.

FIGURE 27. HYDROLOGIC SOURCES

Tidal Surface Water

Tomales Bay. Tides represent a source of energy to estuaries that provides oxygen, sediment movement, and, to some degree, nutrients. Tomales Bay is a 10.8 square-mile shallow, tectonically caused (drowned fault valley) Mediterranean-type coastal estuary (Hollibaugh et al. 1988). Tomales Bay opens at the southern end of Bodega Bay and extends in a southeasterly direction. The bay is approximately 12 miles long and less than one mile wide (RWQCB 2001). The average depth of the bay is less than 20 feet (California Department of Health Services (DHS) 1996; TBWC 2002).

Tides represent a source of energy to estuaries that provides oxygen, sediment movement, and, to some degree, nutrients.

Tomales Bay is a microtidal estuary, which means that the differences between high and low tide are not as pronounced as in other regions of the world such as Alaska's Bay of Fundy, although mesotidal-type tides occur during extreme spring tides in the winter (Harcourt-Baldwin 2003). Within Tomales Bay, the average annual maximum tidal swing is 8.2 feet, with a difference between mean high and mean low tide of about 3.61 feet (KHE 2006a). Tides in Tomales Bay are mixed semi-diurnal, resulting in a daily tidal regime with two flood or "high water" tides and two neap or "low water" tides of varying height or magnitude (KHE 2006a). Relative to the Pacific Ocean, tides are attenuated somewhat in Tomales Bay, with the height of the high tide being generally 0.6 feet less than that at the Golden Gate (KHE 2006a). Tidal prism -- or the volume of water that is exchanged during the typical half-day tide cycle -- has currently been estimated at 990.4 million cubic feet in Tomales Bay, compared to 1.8 billion cubic feet for south San Francisco Bay (CH2M Hill 1990; Watson et al. 1998) and 70.6 billion cubic feet for the entirety of the San Francisco Bay (Barnard et. al. 2006).

Tomales Bay is a relatively well-studied system for a small estuary. Previous hydrographic studies conducted as part of the Land-Margin Ecosystem Research (LMER) program of Tomales Bay have documented the bay's metabolism, its water composition, the dynamics of its nutrient circulation, and the influence of coastal upwelling (TBWC 2003). One of the first such studies was a 1960 hydrographic survey by Johnson et al. (1961). Additionally, Tomales Bay has been the subject of an intensive study into the biogeochemistry, for example, (Smith et al. 1987; 1989; 1991; 1996) (Hollibaugh et al. 1988; 1991) and hydrologic dynamics (Hearn and Largier 1997; Largier et al. 1997a; 1997b; Harcourt-Baldwin 2003) of estuaries. Cole et al. (1990) studied the hydrographic, biological and nutrient properties of Tomales Bay. Chambers et al. (1995) studied the nitrogen and phosphorus dynamics in fringing tidal marshes of the bay.

Circulation – and, therefore, sediment, nutrient, and contaminant dynamics -- in Tomales Bay are predominantly influenced by the Bay's physical shape, tidal cycles, and watershed run-off (TBWC 2003). Historically, circulation within the bay has been characterized as alternating between a classical estuary (net dilutive or "positive" basin) during wet winter months and a hypersaline estuary (net evaporative or "negative" basin) during dry summer months (Hollibaugh et al. 1988). However, as with many other estuaries, advances in computer modeling such as three-dimensional modeling using detailed bathymetric or bottom topography data has revealed that circulation patterns within Tomales Bay and many estuaries are incredibly complex, both spatially and temporally. Several recently developed 3-D hydrodynamic models of Tomales Bay have shown that different transport mechanisms are important in the outer and inner regions of the Bay (Harcourt-Baldwin 2003, (Gross and Stacey 2003).

Gross and Stacey (2003) have developed a three-dimensional hydrodynamic model of Tomales Bay using the TRIM (Tidal, Residual, and Intertidal Mudflat) program through a contract with the San Francisco RWQCB that will provide information to staff that can be used to establish Total Maximum Daily Load (TMDL) goals for loading of pollutants to Tomales Bay. Harcourt-Baldwin (2003) generated a three-dimensional model using a different program as part of Largier's hydrodynamic research conducted as part of Smith and Hollibaugh's LMER studies referenced above. Tomales Bay is often divided into two or three regions – outer, inner, and sometimes middle bays – that are distinguished by differences in bathymetry and distance from its relatively narrow mouth. Most of these models do not incorporate what might be termed the "inner" inner bay, which would cover the Project Area and the undiked marsh north of the Giacomini Ranch, which is shallower, more vegetated, and driven more by fluvial- or creek processes than the open water portions of Tomales Bay (KHE 2006a; see Project Area discussion below).

In the outer portion of the bay, which is characterized by deep channels and shallow shoals or sandbars and strong tidal currents, tides drive the circulation (Harcourt-Baldwin 2003, Gross and Stacey 2003), although heavy freshwater inflows may temporarily affect circulation patterns (Harcourt-Baldwin 2003). Maximum velocities at the mouth are 6.56 feet/second, but these are reduced over neap tides (Harcourt-Baldwin 2003). These strong tidal currents result in complete vertical mixing of waters such at that stratification of tidal and freshwater flows seldom last longer than a day (Harcourt-Baldwin 2003). These modeling results support earlier research that concluded that water in the northern 3.73 miles of the bay exchanges with nearshore coastal waters on each tidal cycle (Hollibaugh et al. 1988). As distance increases from the mouth, the importance of tidal currents decreases relative to other mechanisms, including differences in density between the less-dense freshwater inflow and the more-dense saltwater tides (Harcourt-Baldwin 2003).

In the middle and inner portions of the bay, which are more uniformly shallow than the outer bay, density-driven flow circulation is the dominant process controlling water movement (Harcourt-Baldwin 2003, Gross and Stacey 2003). During the winter, the classic estuarine circulation pattern of gravitational circulation prevails, with less dense freshwater flowing over more dense seawater. Winter freshwater inflow enters Tomales Bay from two primary sources -- Lagunitas Creek near the Project Area and the head of the bay and Walker Creek near the mouth, generally creating a "lens" or layer of the less-dense freshwater on the surface and more dense seawater on the bottom. Lagunitas Creek accounts for 66 percent of the freshwater inflow to Tomales Bay, while Walker Creek represents approximately 25 percent, with the rest of the freshwater inflow coming from the numerous small tributaries to the Bay (Fischer et al. 1996).

The strength and persistence of the stratification depends on the intensity and duration of the freshwater inflow (Harcourt-Baldwin 2003). The estuary rapidly (< 1 day) returns to initial conditions after small freshwater inflow events (Harcourt-Baldwin 2003). After continuous or high inflow events characteristic of the Mediterranean climate's wet winters, continuous freshwater inflow sustains stratification of the middle and inner regions (Harcourt-Baldwin 2003). Recent research in other estuarine systems, including San Francisco Bay, has shown that seasonal variability in stratification may also be accompanied by finer scale variation related to depth and tidal cycle, with unstratified conditions developing during spring tides or in shallower areas of channels and bays (Schoellhamer and Burau 1998). Spatial and temporal variability in stratification within Tomales Bay may result not only from factors such as depth and tidal cycle, but differences in freshwater inflow dynamics following storm events.

While Walker Creek and other small drainages flow into Tomales Bay along its entire length, two-thirds of the Bay's freshwater inflow comes from Lagunitas Creek at the head or southern portion of the bay (Fischer et al. 1996). This large volume of freshwater inflow creates a longitudinal salinity gradient between the southern end or head of the Bay and the northern end or mouth to the Pacific Ocean (Harcourt-Baldwin 2003). This gradient increases flushing or seaward movement of estuarine waters and increases exchange between the middle and outer estuarine regions.

The importance of gravitational circulation within the middle and inner bays decreases during the late spring and summer (Harcourt-Baldwin 2003). As freshwater inflow decreases over the summer, and evaporation increases, estuarine salinity in the middle and inner bays increases, reducing the longitudinal salinity gradient and, consequently, stratification based on difference in density between salt- and fresh waters (Harcourt-Baldwin 2003). The lack of a strong longitudinal salinity gradient within Tomales Bay decreases flushing times from a few days during the winter to approximately 120 days for at least the southern 9 miles of the bay during the summer (Hollibaugh et al. 1988).

In contrast to many other estuaries, however, the density gradient within the estuary does not disappear during the summer, but rather switches from a salinity-driven one to a temperature-driven one (Harcourt-Baldwin 2003). The temperature gradient balances warm temperatures in the middle and possibly inner Bay, which is shallow and more responsive to solar radiation, with upwelling of cold waters in the nearshore Pacific Ocean. Due to strong, persistent offshore winds that churn bottom ocean waters towards the surface during the spring and summer, cold, nutrient-rich water is upwelled along California's central coast (Smith and Hollibaugh 1998, Harcourt-Baldin 2003). The dense, cold upwelling water moves some distance landwards into the estuary with flood tides as a bottom current due to the fact that cold waters are denser than warm surface waters (Harcourt-Baldwin 2003). Significant subtidal intrusions of cold water have been observed a few times during some summers, with colder waters penetrating halfway into the middle and inner bays (Harcourt-Baldwin 2003). These intrusions may represent key sources of nutrients, particularly organic carbon, during the summer to the estuary (Harcourt-Baldwin 2003). Additionally, this longitudinal temperature gradient maintains some type of exchange of waters between at least the outer and middle portions of the Bay (Harcourt-Baldwin 2003), which has important implications for summer water quality. Unlike many other shallow estuaries, including portions of San Francisco Bay, the strong spring winds along the coast, which, on average, can reach as high as 35 miles per hour (mph), do not appear to have a substantial effect on circulation within the Bay (i.e., inducing strong vertical mixing or turnover of waters), perhaps because of the sheltering effect of the steep Inverness Ridge along the western perimeter (Tomales Bay Shellfish Technical Advisory Committee (TBSTAC) 2000).

The very innermost portions of Tomales Bay do not appear to be affected by intrusions of upwelling water, and the lack of a strong salinity or temperature gradient with the middle and outer bays can substantially decrease exchange and increase water residence times (Hearn and Largier 1997; Largier et al. 1997). The lack of connection with the ocean and outer bay can result in at least transient periods of hypersaline conditions, such that salinities slightly exceed salinity in the outer Bay or ocean because solar radiation increases evaporation of waters and concentration of existing salts (Hearn and Largier 1997, Largier et al. 1997). However, despite increases in salinity and temperature relative to the middle and outer bays, longitudinal salinity and temperatures are too weak to increase exchange. This weak temperature gradient between inner and outer portions of the Bay disappears during autumn, when solar radiation decreases, and water temperatures cool in the inner Bay (Harcourt-Baldwin 2003).

Occasionally, this autumn cooling, combined with hypersaline conditions, causes yet another circulation pattern to develop for several days that is common in more tropical estuaries, inverse circulation (Harcourt-Baldwin 2003). Inverse circulation results from evaporation concentrating salts in the now cooler surface waters, which then, because of higher density, sink to the bottom and flow oceanward beneath the less dense ocean waters. Hearn and Largier (1997) speculated that the degree of hypersalinity and the duration of inverse circulation, which results in greater exchange between inner and outer portions of the Bay, may have been greater during historic times than now. This change appears to have occurred, because the Bay has become shallower, and because minimum flow requirements within creeks cause reservoir releases of freshwater throughout the summer, decreasing salinities in the inner Bay (Hearn and Largier 1997, Largier et al. 1997).

In addition to changes resulting from sedimentation, circulation patterns within Tomales Bay also have the potential to be affected by sea level rise. In the 1993 feasibility study (PWA et al. 1993), sea level was predicted to rise at a rate somewhere between 1.5 and 5.0 feet over the next 100 years. NOAA reports that, based on review of historic (1854-1999) water level gauge data, sea level has risen at a rate of 0.00328 to 0.0079 feet/year over the last century and that sea levels have risen 0.007 feet/year in San Francisco since 1906 (NOAA 2001) *in* KHE 2006a). Based on 25 years of Point Reyes water level records, NOAA predicts a local sea level rise rate of 0.0082 feet/year in this region (NOAA 2001 *in* KHE 2006a). Based on recent satellite altimetry studies, Cazenave and Narem (2004) report a "very accurate" sea level rise rate of 0.0092 ± 0.0013 feet/year for the 1993-2003 decade. This rate is notably higher than what NOAA's rate of change based on measured changes in tide gauges over the preceding half century (KHE 2006a). In 2005, the USGS completed a relative coastal vulnerability study that depicted most of Tomales Bay as having low to moderate vulnerability to sea level rise (Pendleton et al. 2005). Most recently, researchers from University of Arizona, the National Center of Atmospheric Research, and other institutions suggest that accelerated melting of the Arctic and Antarctic ice caps and Greenland glaciers could raise sea level by as much as 3 feet by the end of this century and 13 to 20 feet in coming centuries (Overpeck et al. 2006; Velicogna and Wahr 2006).

Ultimately, circulation patterns within estuaries drive not only on the movement and exchange of tidal and freshwater within a system, but the movement and deposition of suspended sediment and associated nutrients and contaminants and even the abundance and diversity of biota such as phytoplankton, zooplankton, invertebrates, and fish. These relationships result from the hydrodynamic effects of circulation patterns such as landward movement of ocean currents, vertical mixing of surface and bottom waters, net upward currents, and salinity structure of waters, particularly low salinity or transitional zones (Kimmerer 2004). Kimmerer (2004) recently summarized decades of research on relationships between suspended sediment and biota and circulation and/or salinity patterns in San Francisco Bay, and another LMER project in the Columbia River Estuary in Oregon has also extensively investigated this estuarine phenomenon. This subject is discussed further under Water Resources – Water Salinity and Estuarine Turbidity Maxima.

Lagunitas Creek. While earlier studies reference the "Inner Bay" of the Tomales Bay watershed, the boundaries for most of these studies or models end well ocean-ward of the Project Area. The Project Area is located in an area of the estuary that would constitute what could be called the "Inner Inner Bay." This "Inner Inner Bay" represents one of the largest estuarine transition zones in Tomales Bay, areas characterized by the dynamic interface both seasonally and interannually between freshwater and saltwater. This portion of the Bay is characterized by even shallower bathymetry than the Inner Bay, prominent gravel and sand bars in creek channels, and large expanses of undiked tidal marsh and intertidal mudflat, some of which is being actively colonized by Pacific cordgrass (*Spartina foliosa*). In actuality, the "Inner Inner Bay" is part of the Lagunitas Creek – and, to a lesser extent, Fish Hatchery Creek – alluvial delta and is, therefore, dominated more by fluvial than tidal processes (KHE 2006a). The portion of Lagunitas Creek in the Project Area bisects the Giacomini Ranch into two "pastures:" East and West (Figures 2, 27).

The importance of fluvial geomorphic processes within the tidally influenced sections of Lagunitas Creek is evident in the series of gravel and sand bars that have formed from the Green Bridge to the open water portions of Tomales Bay in response to episodic flooding. These gravel and sand bars strongly regulate circulation patterns in this reach of Lagunitas Creek. As with any dam, gravel bars or sills in estuaries can impound waters and disrupt tidal circulation patterns through causing tidal truncation or reduction in the extent of drainage during low tides and increasing water residence time. While, from a tidal perspective, these sills limit drainage during low tides and decrease the amount of exposed mudflat available for species such as shorebirds, from a fluvial perspective, these sills create deepwater, almost lagoonal-type pools that are somewhat analogous in function to pools found in creeks in the upper portion of the watershed. Both types of pools provide important permanently flooded habitat for many aquatic species. Retention of water upstream of gravel bars can reduce water quality through decreasing dissolved oxygen concentrations, but tidal exchange during high tides can decrease the potential for stagnant conditions to develop.

There are two major gravel or sand bars within the Project Area that truncate the lower range of tides and control the depth of upstream residual pools: one is located near where the Giacomini Ranch cows cross Lagunitas Creek to reach the West Pasture (cattle crossing), and the other occurs just south or upstream of the Giacomini Ranch north levee. Within this section of creek, the gravel bars appear to function as a series of "dams" that truncate tidal amplitude and preclude upstream waters from draining completely.

TABLE 6. TIDAL DATUMS FOR NOAA TIDE GAUGE, TOMALES BAY AT INVERNESS TIDAL EPOCH: 1960-78

	MLLW Datum (feet)	NAVD88 Datum (feet)
MHHW	5.34	5.83
MHW	4.64	5.13
MTL	2.76	3.25
NGVD29	2.15	2.64
MLW	0.88	1.37
MLLW	0.00	0.49

A comparison of water levels between the nearest NOAA tidal gauging station in Tomales Bay, Inverness Park (Table 6: Datums), and the portion of Lagunitas Creek within the Project Area indicate that, while the stream gradient is relatively flat through the Project Area, the lower range of tidal amplitude becomes progressively more truncated as distance from Tomales Bay increases (KHE 2006a; Figure 28). Figure 28 is a schematic longitudinal profile of channel bed and top of bank elevations, as well as water levels, along Lagunitas Creek through the Project Area from the Green Bridge at the southeastern end of the Project Area to the Ranch's northern levees at the northern end of the Project Area. This graphic shows the weir-type effect that these gravel bars have on water levels, with the base or minimum water levels observed increasing in elevation in a step-wise manner in an upstream direction (KHE 2006a). There is only a very small truncation of high tides or the upper part of the tidal range, with high water levels the portion of Lagunitas Creek within the Project Area relatively similar to those predicted at Inverness (KHE 2006a). This information suggests that MLW and MLLW elevations for the portion of Lagunitas Creek in the Project Area would differ from that of the predicted tides at Inverness, but the other tidal elevations would remain similar (KHE 2006a).

FIGURE 28. TOPOGRAPHY AND BATHYMETRY OF LAGUNITAS CREEK CHANNEL BANKS AND BOTTOM

Typically, at MHW, tidal waters would begin to flood onto marshplains. However, in the reach of Lagunitas Creek within the Project Area, the Giacomini Ranch levees preclude tidal inundation of its historic marshplains. In addition, past deposition of fill in the Green Bridge County Park and White House Pool County Park have also largely eliminated the potential for tidal influence at higher tides in these historic marsh areas. A list of infrastructure and management practices that negatively affect both tidal and fluvial or freshwater hydrologic processes can be found in Table 7. Between Tomales Bay and White House Pool, Lagunitas Creek is wide and relatively uniform in shallowness, although deeper portions of the channel or thalwegs do occur.

The broad and long gravel bar just south of the Giacomini Ranch north levee controls the lowest water level observed between the north levee and the cattle crossing location so that water levels do not drop below approximately 1.9-feet NAVD88, even though portions of the channel are 0-feet NAVD88 (KHE 2006a; Figure 28). As will be discussed in more detail under Water Resources – Water Salinity, circulation patterns within this reach vary seasonally, but, based on long term monitoring data, are typically either well-mixed (fresh in the winter and saline in the late summer-fall) or partially stratified (partial stratification of freshwater at the water surface), although strong stratification occurred very infrequently. The shallowness of this reach, combined potentially with currents and wind, appear to discourage stratification.

Upstream of the cattle crossing location and another prominent gravel bar, the creek becomes noticeably narrower and deeper, functioning almost like what is called a glide with relatively deep water and low velocities. The cattle crossing gravel bar again increases the amount of truncation in the observed low or minimum tidal water levels within Lagunitas Creek at approximately 2.8-feet NAVD88 (KHE 2006a; Figure 28). Circulation patterns within this reach differ noticeably from those downstream. While both upstream and downstream reaches are well-mixed and fresh during winter and spring, the White House Pool reach becomes strongly to at least partially stratified during summer and fall, probably due to the decreasing, but continued, influence of freshwater inflows. The degree of stratification may also be driven by tidal cycle, as other researchers have noted more stratification during neap tides or low tide conditions (Reed and Donovan 1994; Schoellhamer 2001).

Stratification within this reach during summer and fall could result either from reestablishment of gravitational or classic estuarine circulation driven by the opposing forces of tidal currents and freshwater inflows – the pattern in much of the open waters of Tomales Bay – or stratification or resorting of “pooled” waters based simply on vertical differences in density. While the strength of tidal currents decreases at least by tenfold in the “inner” bay relative to the mouth of Tomales Bay (Smith et al. 1971), the presence of longitudinal salinity gradient between the Green Bridge and White House Pool during the summer and fall suggests that gravitational circulation might be occurring despite the shoaling effect on tidal flows caused by the downstream shallow creek channel and gravel bars. Longitudinal salinity gradients, particularly strong gradients, are associated with gravitational circulation patterns (D. Schoellhamer, USGS, *pers. comm*.).

Near the Green Bridge, Lagunitas Creek is primarily a fluvial system. Scour pools within this reach appear to be partially stratified for most of the summer and fall, although strong stratification may occur during higher high tides. Even further upstream, Lagunitas Creek begins to transition into more of a freshwater system influenced by tides such that there is, at least in downstream portions near the Coast Guard wells, a time lag between increases in water levels from tides and the subsequent shift from freshwater (salinities < 0.5 parts per thousand or ppt) to brackish water (salinities ≥ 0.5 and < 2.0 parts per thousand or ppt) conditions (KHE, unpub. data).

Fish Hatchery Creek. Fish Hatchery Creek is the primary tributary within the West Pasture of the Giacomini Ranch (Figure 27). The Giacominis installed a one-way tidegate in the West Pasture north levee near Sir Francis Drake Boulevard, however, at some point, this gate began to malfunction and allow some tidal waters into the pasture (Table 7). Muted tidal flushing in the West Pasture has resulted in reduced tidal prism, with prism currently estimated at 8.1 acre-feet at MHW based on hydrologic modeling (KHE 2006a).

Beyond the Giacomini Ranch, Fish Hatchery Creek continues to run along the western perimeter of Tomales Bay until it reaches the Bay itself. As with Lagunitas Creek, gravel bars within the undiked portion of Fish Hatchery Creek also appear to act as small “weirs,” controlling the lower tidal range in the southern sections of the creek (KHE 2006a). Just downstream of the Giacomini Ranch, low tides are controlled at approximately 3.0-feet NAVD88 (KHE 2006a).

TABLE 7. HYDROLOGIC INFRASTRUCTURE AND MANAGEMENT PRACTICES IMPACTING IMPEDIMENT SURFACE FRESHWATER HYDROLOGIC PROCESSES IN THE PROJECT AREA AND UPSTREAM PORTIONS OF THE WATERSHED

Note: For larger creeks, only impediments on mainstem or central portions of creek are listed. Impediments are listed from upstream to downstream. Multiple similar impediments in the same area of watershed are sometimes denoted by total number of impediments in parentheses, for example (2).

Creek	Project Area: Hydrologic Infrastructure/ Management Impediment: Approximate Location	Upper Watershed: Hydrologic Infrastructure/ Management Impediment: Approximate Location
Mainstem Lagunitas Creek	1. *Bridge*: Green Bridge at State Route 1	1. *Dams*: Lagunitas, Phoenix, Alpine, Kent, Nicasio (5)
	2. *Levees*: Past Fill Placement on Green Bridge County Park, Levee Road, East Pasture Levee and Creek Bank Fill, Past Fill Placement on White House Pool County Park, West Pasture Levee (5)	2. *Levees*: Sir Francis Drake Blvd and Historic Railroad Grade (2)
	3. *Management*: Giacomini Cattle Crossing	3. *Floodplain Development*: Samuel P. Taylor State Park
	4. *Management*: Infrequent Discharge of Ditch Water to Creek	4. *Levee*: Platform Bridge Road
	5. *Management*: Levee Maintenance – East Pasture	5. *Bridges*: SFD at Platform and Pt. Reyes-Petaluma Road (2)
	6. *Management*: Levee Maintenance – West Pasture	6. *Floodplain Development*: Sand Processing Plant
		7. *Water Diversion*: Gallagher, Downey Well, and Coast Guard Wells (4)
		8. *Water Diversion*: Genazzi Ranch
		9. *Management*: Cattle in creek at Genazzi Ranch
Mainstem Bear Valley Creek	1. *Culverts*: Bear Valley Road, Levee Road, Former west outlet – Bear Valley Creek, Silver Hills drainage (4)	1. *Levees*: Bear Valley Trail, Bear Valley Road (see Project Area), Limantour Road, Past Fill Placement on west side of creek (4)
	2. *Levees*: Bear Valley Road, Olema Marsh parking, Past Fill Placement in north portion of Olema Marsh near Levee Road, Levee Road, Past Fill Placement in White House Pool County Park (5)	2. *Culverts*: Bear Valley Trail, Rift Zone Trail, Vendanta Ranch, Red Barn Road, Visitor Center's Road (5)
	3. *Management*: Dredge former west outlet at Bear Valley Creek	3. *Water Diversion*: NMWD right, but no use
	4. *Bridge*: Footbridge in White House Pool County Park	4. *Floodplain Development*: Seashore Headquarters Complex
	5. *Floodplain Development*: WHP park	5. *Creek Realignment*: Maintenance Yard
		6. *Floodplain Development*: Maintenance Yard
		7. *Management*: Dredged below Maintenance Yard
Tomasini Creek	1. *Water Diversions*: at north end near outlet to Tomales Bay	1. *Water Diversions* (2)
	2. *Culvert*: Mesa Road	2. *Culvert*: Road crossing on tributary (3)
	3. *Levees*: Mesa Road, Tomasini Creek berm, Past Fill Placement on North Side at RR Grade	3. *Levee*: Ranch Road
	4. *Bridge*: at Hunt Lodge	4. *Dams*: West Marin Landfill Ponds (2), Livestock ponds (2)
	5. *Management*: Levee Maintenance	5. *Culvert*: State Route 1 crossing
	6. *Tidegate/Culvert*: at East Pasture North Levee	
Fish Hatchery Creek	1. *Culvert*: Sir Francis Drake	1. *Water Right Diversions* (3)
	2. *Floodplain Development*: Private Residence	2. *Culverts*: Vallejo Avenue road crossings of mainstem and tributary (5)
	3. *Management*: Dredging downstream of SFD	3. *Levee*: Vallejo Avenue
	4. *Water Diversion*: Giacomini Ranch	4. *Floodplain Development*: Homes (3)
	5. *Management*: Maintain Creek Crossing	5. *Bridge*: Driveway crossing of mainstem creek
	6. *Tidegate/Culvert*: at West Pasture North Levee	6. *Floodplain Development*: Commercial and residential development near Sir Francis Drake Boulevard (15)
	7. *Management*: Cattle in creek	7.
1906 Drainage	1. *Culvert*: San Francis Drake	1. *Culvert*: Private Road Crossing
	2. *Realigned Channel*: Private Residence	2. *Levee*: Private Road
	3. *Floodplain Development*: Private Residences (2)	3. *Floodplain Development*: Private residences (2)
	4. *Culvert*: into West Pasture	4. *Realigned Channel*: Ditched on north side of Sir Francis Drake
	5. *Realigned Channel*: West Pasture	
	6. *Management*: Dredging downstream of residence	
	7. *Floodplain Development*: Dredge spoil disposal area	
	8. *Management*: Cattle in creek	

The tidegates on Fish Hatchery Creek in the West Pasture reduce amplitude of both the low and high tides (KHE 2006a). The lowest water levels measured just inside the West Pasture in Fish Hatchery Creek are 3.25 feet NAVD88 (KHE 2006a). This attenuation continues as the stream gradient increases, with the lowest water levels measured on a tributary to Fish Hatchery Creek, the West Pasture Old Slough, at 4.0 feet NAVD88 midway through the West Pasture (KHE 2006a). The tidegates also truncate the upper portion of the tidal range, peaking at approximately 5.25 feet NAVD88 (KHE 2006a). In 2003, the tidegates on Fish Hatchery collapsed and began to erode the levee. During this period, the malfunctioning appeared to allow more even tidal exchange than occurred previously, including into large portions of the West Pasture freshwater marsh (See more detailed discussion under Giacomini Ranch and Water Salinity). After the tidegates were replaced in the fall of 2003, tidal exchange decreased again (KHE 2006a).

Fish Hatchery Creek tidegate

Circulation patterns in Fish Hatchery Creek are largely dictated by its shallow nature. Waters are usually shallow (<25 cm) and well-mixed or weakly stratified, although strong stratification occurs periodically within areas. This periodic stratification results from movement of the "salt wedge," or edge of tidal influence, landward over the season, as the volume of permanent freshwater flows decrease.

The West Pasture Old Slough is a tributary to Fish Hatchery Creek that appears to be a remnant historic tidal slough that has been converted in its upstream reaches into a ditch to channel seasonally high surface run-off from a seep on the Gradjanski property (Figure 27). It connects with Fish Hatchery Creek in the northern portion of the West Pasture, thereby leading to also have a muted tidal regime (Figure 27). The slough is typically well-mixed and strongly brackish to saline (~22.4 to 30 ppt) in the late summer and early fall and either well-mixed or strongly stratified, depending probably on tidal conditions and freshwater inflow, and during the winter, spring, and early summer, when water salinities are fresh to brackish (~0.2 to 21.8 ppt; Parsons, *in prep*.). Salinities are frequently higher in upstream reaches of the slough than in downstream reaches that are closer to the tidegate (Parsons *in prep.*). This pattern in salinities may reflect longer residence time of tidal waters that can extend into this reach, combined with potentially a backwater flooding effect such that lower salinity waters from Fish Hatchery Creek flow back up into the West Pasture Old Slough when seasonal freshwater flows in the slough decrease appreciably (Parsons, *in prep*.).

Tomasini Creek. Tomasini Creek is the primary tributary within the East Pasture of the Giacomini Ranch (Figure 27). As with Fish Hatchery Creek, the tidegate and flashboard dam structure on Tomasini Creek at its outlet to Lagunitas Creek at the north levee has been less than effective in eliminating tidal exchange (Table 7). The gate-dam structure truncates low tides or controls the extent of drainage during low tides to approximately 2.0-feet NAVD88, at least 1- to 2 feet above the deepest portions of the channel (KHE 2006a). However, similar to Lagunitas Creek, there was still substantial tidal exchange over the upper portion of the tidal range, with only minor reduction of the peak flood-tide water levels of less than 0.5-feet (KHE 2006a). Peak high tides within the diked portion of Tomasini Creek reach 7 feet NAVD88 (KHE 2006a). On some of these high tides, waters from Tomasini Creek flood into the East Pasture through a culvert in the Tomasini Creek berm into a borrow ditch that runs along the berm's western side (L. Parsons, NPS, pers. obs.). Monitoring of water levels near the Giacomini Hunt Lodge show tidally driven fluctuations in water level when high tide water levels exceed the base level of 4.5-feet NAVD88 (KHE 2006a).

Based on results of hydraulic and hydrodynamic modeling, the tidegate-dam structure did not appear to be the only feature that is acting to impound water (KHE 2006a). As with Lagunitas and Fish Hatchery Creek, several topographic features within the creek channel appear to be control low or minimum water levels – one between the tidegate and the Giacomini Hunt Lodge and one closer to Mesa Road (KHE 2006a). Close to Mesa Road, an extended debris and sediment jam that is just downstream of the Mesa Road culverts at a point where the creek gradient flattens appears to hydrologically disconnect the lower reach from the upper reach, at least during low flow conditions, thereby limiting water and tidal exchange. Surface water often disappears just below the debris jam during the late summer and fall until the creek reaches the Giacomini Hunt Lodge.

As with Lagunitas and Fish Hatchery Creeks, the creek appears to be well-mixed and largely fresh during the winter and early spring (NPS, unpub. data). Starting in late spring and extending through late fall, most of the creek remains well-mixed -- or at least partially stratified -- but salinities are more brackish, varying both spatially and temporally along the creek, seemingly in response to tidal cycles and decline in surface and subsurface creek flow (NPS, unpub. data). The downstream end near the tidegate is typically well-mixed and brackish throughout the year. Just upstream, the creek is generally well-mixed or partially stratified, but occasionally becomes strongly stratified (NPS, unpub. data). During some of these periods when this reach is strongly stratified, bottom salinities exceed that of upstream and downstream (bayward) monitoring locations, suggesting that saline waters may be pooling in this section of creek, perhaps in response to an earthen sill or other topographic feature downstream. As with Fish Hatchery Creek, a "salt wedge" appears to move up the creek as freshwater inflows decline during the summer and fall. The advance of the "salt wedge" appears to be blocked by the debris and sediment jam south of Mesa Road, however. While early modeling results suggested that, based on creek gradient, tidal influence could extend as far as Mesa Road (KHE, unpub. data), creek waters near Mesa Road are always fresh and well-mixed (NPS, unpub. data).

Another factor that influences salinity in Tomasini Creek is the presence of perennial groundwater flow from the adjacent Point Reyes Mesa (KHE 2006a). Groundwater seepage may contribute to creek hydrology through run-off from hillside springs, seepage along the base of the Mesa, and subsurface groundwater inflow. Salinities simulated from modeling based on creek flows and attenuated tides, but not groundwater, suggests that the contribution from groundwater to the Tomasini Creek water budget may be considerable (KHE 2006a). Based on modeling, salinities near the Giacomini Hunt Lodge during the summertime with typical low summer flows should range from 20.5 to 25.0 ppt, but actual salinities recorded during monitoring by the Seashore show that salinities range from 15.0 to 18.0 ppt in both surface and bottom waters (KHE 2006a).

Giacomini Ranch. Tidal influence within the West and East Pastures has been significantly minimized through diking and tidegates (Table 7). However, leakiness of the Fish Hatchery Creek tidegate has enabled at least irregular tidal surface overbank flooding of the northern portion of the West Pasture and the northern and central portions of the West Pasture freshwater marsh, as well as depressional features in the central portion of the pasture that appeared to be remnant tidal channels.

West Pasture: Based on water level data collected within the marsh, tidal influence appears to occur in the marsh when tides in the diked area equal or exceed 5.25 feet NAVD88, the maximum tidal range currently permitted by the modified tidegate at the north levee (KHE 2006a). Currently, these tidal events are relatively infrequent and probably only occur when salinities in undiked areas exceed 6.25 to 6.5 feet NAVD88 (KHE 2006a). These extreme high tides occur sporadically throughout the year, but are highest between December and March, when they are often compounded by high volumes of freshwater flow from rainfall. Saltwater entering the freshwater marsh from the north end of the marsh appears to preferentially flow alongside Sir Francis Drake Boulevard before spreading through sheetflow to the central and eastern portions of the marsh, the lowest elevations within the marsh. Because the marsh is a highly vegetated depressional basin, drainage of tidal flows from the marsh does not appear to occur during low tides or even within days as flows recede, but rather to pond for perhaps as long as several months. A more detailed discussion of this occurs in Water Resources –Water Salinity.

East Pasture: The leakiness of the Tomasini Creek tidegate has also created some tidal influence within the diked pasture, albeit more indirectly. On some high tides, waters from Tomasini Creek flood into the East Pasture through a culvert in the Tomasini Creek berm into a borrow ditch that runs along the berm's western side (NPS staff, pers. obs.): these waters often overspill onto the pasture and have created essentially a sparsely vegetated, saline flat that is commonly used during the winter and spring by shorebirds and waterfowl. Some of these waters flow into the pasture's drainage ditch system, which is typically used for storing freshwater for irrigating the pastures during the summer. Otherwise, as with the southern portions of the West Pasture, direct tidal influence may be limited to large storm events that occur during extreme high tides (e.g., 1982 and 2006) that cause overbank flooding of levees into the pastures. Because of the difficulty in estimating waters that enter the East Pasture from Tomasini Creek episodically through this culvert, the very limited tidal prism that does exist currently could not be accurately estimated.

Limited areas of both the East and West Pasture that immediately border Lagunitas Creek also appear to have some very indirect tidal influence through hydraulic connectivity of the pastures' groundwater table with the rise and fall of tides in Lagunitas Creek (See Water Resources – Groundwater for more detailed discussion).

Olema Marsh and Bear Valley Creek. Olema Marsh once represented an integrated tidal marsh complex with the Giacomini Ranch (Figure 21). Tidal influence was believed to extend as far upstream on Bear Valley Creek as the park's administrative headquarters during extreme tide conditions. Construction of the levee across the mouth of Olema Marsh in 1892 for construction of Sir Francis Drake Boulevard or Levee Road hydrologically disconnected the marsh from the Giacomini Ranch (Table 7). While the flow path of Bear Valley Creek through marsh has not remained constant in the intervening years, currently, the box culvert on the downstream end at Levee Road just before the creek's confluence with Lagunitas Creek acts as a grade control structure that reduces the range of tidal exchange into the marsh (KHE 2006a; Figure 27; Table 7). The culvert invert limits tidal exchange to those exceeding 4.5-feet NAVD88 (KHE 2006a). As with many of the other creeks, the culvert does not appear to attenuate or only minimally attenuates affect the upper portion of the tidal range (KHE 2006a). Prior to the 1998 flood, Bear Valley Creek apparently flowed out of a culvert underneath Levee Road that is on the western perimeter of Olema Marsh near the White House Pool County Park (Figure 27). Currently, this channel is disconnected from the marsh through a build-up of sediment between the marsh and the western culvert, and the culvert now only contains flows from the Silver Hills drainage, which has been redirected into a ditch on the south side of Levee Road. Because sediment deposition within the culvert has raised the elevation of its "bottom," tidal influence in the Silver Hills drainage channel would be limited to some of the highest high tide events, exceeding 6.9 ft NAVD88 (~ 7 ft MLLW; G. Kamman, KHE, pers. comm.).

Fluvial Surface Water or Fresh Water

Lagunitas Creek. The 83.1 square mile Lagunitas Creek watershed is the largest watershed in Tomales Bay (KHE 2006a). Two-thirds of the freshwater inflow to Tomales Bay comes from Lagunitas Creek and its tributaries (Fischer et al. 1996). Its tributaries, Olema Creek, Bear Valley Creek, and Haggerty Gulch, are located, from east to west, respectively, along the southern margin of the Project Area. Lagunitas Creek drains the Coast Range mountains located east and southeast of the Project Area (Figure 20). The watershed is underlain by a variety of Franciscan Complex rocks, mostly greywacke and metavolcanics.

Lagunitas Creek is a perennial system. The stream gradient of the creek within the Project Area is relatively flat. Other than the large bend to the west at the south end of the Project Area, its course is relatively straight and lacks sinuosity, as is common with fluvial-dominated deltaic systems. Considerable debate centers around the reason for the large, almost unnatural 90 degree bend in Lagunitas Creek near White House Pool: it may be due to the alluvial fan present near the Giacomini Ranch dairy or related somehow to the fault. The creek is strongly to moderately entrenched in the Project Area due to presence of the Giacomini Ranch levees and steep creek banks on the south side of Lagunitas Creek along Levee Road. East Pasture levees upstream of the old summer dam location range from 14- to 17-feet NAVD88 in height and drop to as low as 8- 10 feet NAVD88 at their northern end (KHE 2006a). Around White House Pool and the location of the old summer dam, the pastures are graded at levels equivalent to adjacent levees, at about 11- to 12 feet NAVD88 in elevation (KHE 2006a).

Much of the area between Levee Road and Lagunitas Creek was filled since construction of the original embankment for what is now Levee Road and is only slightly lower in elevation than the East Pasture levees (~10-11 feet NAVD88). Levee Road itself ranges from 13- to 15 feet NAVD88 in the residential area. The West Pasture levee ranges from 12-feet at the south end to 10-feet at its northern end (KHE 2006a). Beyond the Giacomini Ranch, Lagunitas Creek has formed natural alluvial levees along its creek bank that are considerably lower in elevation (~ 7.1 feet NAVD88; PWA et al. 1993). Despite these geomorphic constraints, Lagunitas Creek still overtops the levees and creek banks with varying frequency (see Water Resources-Floodplains for more discussion). These flows play an important role in sediment delivery and transport through the Project Area, as well as influencing channel, floodplain, and delta form (KHE 2006a).

While flow may be perennial, Lagunitas and other creeks still have flow patterns characteristic of systems in Mediterranean climates. Creek flow, measured at USGS gauging station near Pt. Reyes Station, averages 357 cubic feet per second (cfs) in February to as low 5.5 cfs in September (USGS 2004). During the severe drought of 1976-77, average monthly summer flow rates dropped to as low as 0.45 cfs (KHE 2006a). Flow is now regulated by the State Water Resources Control Board (SWRCB) through Decision 95-17, which has mandated minimum creek base flow at Samuel P. Taylor State park gage during the summer from storage reservoir releases of 8 cfs during normal rainfall years and 6 cfs during dry years. In November, minimum flow requirements increase to 20 and range between 16 to 25 cfs between November and April 30.

Lagunitas Creek inflow to the Project Area has been significantly altered by historic water development in the basin (KHE 2006a). Approximately 70 percent of the waters from this subwatershed are controlled by dams (PWA et al. 1993). A list of infrastructure and management practices affecting fluvial or freshwater creek processes in Project Area subwatersheds can be found in Table 7. Water development was initiated in the

Lagunitas Creek watershed with the construction of Lake Lagunitas in 1873 (350 acre-feet [AF] of capacity). This was followed by damming to form Phoenix Lake in 1905 (411 AF of capacity). Beginning in 1875, several water companies were created and provided water to the rural communities of Point Reyes Station, Inverness Park, and Olema (SWRCB 1995). Starting in 1955, flow from about 40 percent of the watershed area started entering six water catchment reservoirs (KHE 2006a). Reservoir construction and expansion continued through 1982 with the following facilities:

- ***Alpine Lake*** (1918) with a capacity of 3069 AF;
- ***Alpine Lake*** expansion to 4600 AF in 1924;
- ***Alpine Lake*** expansion to 8900 AF in 1941;
- ***Kent Lake*** (1953) with a capacity of 16,050 AF;
- ***Nicasio Reservoir*** (1960) with a capacity of 22,430 AF; and
- ***Kent Lake*** expansion to 32,900 AF in 1982.

The effect of these dams on hydrogeomorphic processes of Lagunitas Creek has not been specifically studied. However, in arid portions of the country, dams operated for water supply and/or flood control have resulted in a reduction in the frequency and strength of peak instantaneous flows, an increase in the duration of bankfull or ordinary high water flows, and a drastic reduction in summer low flows and gravel/sediment recruitment ((Fenner et al. 1985; Stromberg and Patten 1990; Johnson 1992; 1994; 1998); (Friedman et al. 1998). In additions, dams and levees often reduce the lateral migration rate of meandering systems (Johnson et al. 1971; Bradley and Smith. 1986; Rood and Mahoney 1990; Friedman et al. 1998). Recent studies on Lagunitas Creek have investigated possible problems with a “fining” of the sediment substrate and a reduction in sediment recruitment in the upper reaches downstream of the dams, which may be related to sediment trapping – particularly coarse sediments – by the dams (Stillwater Sciences 2004);. The dams may also be affecting the frequency and intensity of peak flows within the creek ((Stillwater Sciences 2004). As with many other river and creek systems, the effect of damming on the watershed has been compounded by other hydrologic alterations, including past mining of the floodplain terrace for sand (> 2 stream miles upstream from Project Area) and downstream appropriative and riparian water rights stream diversions by property owners.

The Giacominis undertook their own water development for the purpose of irrigating pastures. The following summary is excerpted from a SWRCB water rights hearing report for Lagunitas Creek (1995):

> *“Giacomini…graded and leveled the land, and used water from Lagunitas Creek to leach the salt out of the soil. Giacomini drilled two wells on the southwest portion of the property to obtain water; however, both wells produced water that was too brackish for irrigation. Giacomini then attempted to divert water directly from Lagunitas Creek at the most upstream location adjacent to his property; however, the tidal influence in Lagunitas Creek caused the water to become too salty about May, when the stream flow diminished. Since the mid-1940’s, Giacomini has constructed an earthen dam in the creek to prevent saltwater intrusion and to provide freshwater for irrigation.”*

The Giacominis diverted water from Lagunitas Creek under claim of a riparian water right (KHE 2006a). An appropriative water right license was also issued by the SWRCB in 1950. The riparian right lays claim to a maximum pumping capacity of 350 cfs year-round. The appropriated right is for 2.67-cfs between May 1 and October 1. In addition to maintaining a freshwater pool for diversion, the Giacomini summer dam ultimately ended up benefiting NMWD by preventing salt water from moving upstream of the Green Bridge during the summer and fall: NMWD constructed groundwater wells for municipal water supply directly upstream of Green Bridge in 1970. The summer dam was historically approximately 100-feet long, 10-feet high, and 60-feet wide at the base. It created a pond that was about 7-feet deep and extended about 1.75-miles upstream, inundating approximately 17 acres (SWRCB 1995). As part of SWRCB Decision 95-17, construction of the dam ended in 1997. The Giacominis now receive irrigation water (approximately 2-cfs during the May 1 through November 1 period) from the NMWD “Downey” well located approximately 0.9-miles upstream of Green Bridge (Table 7). When the Giacomini Ranch is turned over to the Park Service in 2007, irrigation of the pastures will cease, and 2.00 cfs will revert to Park Service management. The remaining 0.67 cfs of the Giacomini’s original water right was purchased from the Giacominis by NMWD in the late 1990s.

Olema Creek. Only the mouth of Olema Creek falls within the Project Area, but a short description is provided, because of the creek’s size and proximity to the Project Area. It flows directly into Lagunitas Creek just southeast of the Giacomini Ranch old summer dam location. The Olema Creek watershed is an elongated 14.7-square mile drainage basin occupying the San Andreas Fault zone immediately south of the Project Area

(KHE 2006a; Figure 27). Olema Creek is the largest tributary to the Lagunitas Creek subwatershed that is not dammed with the Lagunitas Creek confluence near the upstream boundary of the Project Area. The Olema Creek basin is approximately 9-miles long and 1- to 2-miles wide. Approximately 70 percent of the drainage area consists of runoff from the west flanks of Bolinas Ridge, while the remainder of the watershed occupies the eastern slopes of the Inverness Ridge. Within this basin, the Bolinas Ridge is underlain by Franciscan Complex bedrock, and the Inverness Ridge is composed of fine-grained marine sediments of the Tertiary-aged Monterey Formation (see Figure 20). A mixture of modern/historic alluvial, estuarine, and freshwater marsh deposits blankets the valley floor of this drainage.

Stream gradient of Olema Creek near the Project Area is relatively flat, with the creek following a rather straight – and, in some areas, braided – course. In recent years, the channel has aggraded considerably in its lower sections, causing the creek to jump out of its alignment of the past 80 years, and reestablish a distributary floodplain or network of secondary channels in Stewart Flat in the low-lying floodplains of Olema Creek between the town of Olema and Point Reyes Station. The creek appears to be moving closer toward historic conditions, when moderately sized riparian forests flourished along a somewhat sinuous Olema Creek, as shown in a map of the Berry grant produced in 1854 (Livingston 1995). This depiction is supported by a description by Schofield (1899) of Olema Creek as having banks that are “thickly grown with brush and trees. The last two miles of the creek run through low swampy land, with its banks most of the way heavily lined with willows.” Some historical accounts also refer to an “Arroyo Olemus Lake” or Olema Lake, which most likely occurred at Stewart Flat (Niemi and Hall 1996). This “lake” may have been subsequently drained by construction of the Olema Canal, which straightened the section of Olema Creek between Olema and Lagunitas Creek (Niemi and Hall 1996). Currently, Olema Creek is bridged at Levee Road near its confluence with Lagunitas Creek.

The lower two-thirds of the Olema Creek watershed are perennial. The flow is sustained during the summer months principally by the perennial tributaries draining the Inverness Ridge. Tributary streams off the Bolinas Ridge are typically intermittent during the summer months. Streamflows during the winter runoff period, as determined at Olema, typically reflect baseflow conditions of about 5- to 10 cfs, with peak storm flows of several hundred to more than 1,000 cfs (Questa Engineering Corp. 1990). Because of the valley’s linear nature, the watershed responds rapidly to rainfall events. Ketcham (1998) indicates that there is an approximate 3-hour lag time on Olema Creek between the onset of significant rainfall events and peak discharge. The estimated mean annual water yield for Olema Creek (at Bear Valley Road) is approximately 20,800 acre-feet (Questa Engineering Corp. 1990). This translates to an average annual flow of just under 29-cfs. However, seasonal flow variability displayed in monitoring data indicates summer baseflow rates ranged 0.1- to 1.0-cfs over dry to near-normal water year types (Questa Engineering Corp. 1990). There is also tidal influence on Olema Creek on the downstream 0.3 miles before it joins with Lagunitas Creek (B. Ketcham, Seashore, *pers. comm*., 2006).

Bear Valley Creek. Similar to Olema Creek, Bear Valley Creek occupies the San Andreas Fault zone valley. Within the fault zone, Bear Valley Creek is separated from Olema Creek by a 120-foot medial ridge composed of marine terrace deposits. Approximately half of the headwaters area of this 4.1-square-mile subwatershed is underlain by Monterey Formation sediments, while the other half lies atop granitic bedrock (KHE 2006a).

Hydrology of this watershed derives not only from surface runoff from the relatively steep upper watershed and more level floodplains in the Olema Valley, but from groundwater originating from the Inverness Ridge. The upper reaches of Bear Valley Creek and its tributaries are single-threaded, moderately entrenched sections that are characterized by a well-defined riparian corridor. These sections are constrained by the steep topography of ravines along Inverness Ridge and the historic ranch roads that are now being used for the Seashore’s Bear Valley Trail. The lower portions of Bear Valley Creek consist of single-threaded or multi-threaded channels that are exceptionally shallow. Approximately 2,300 feet upstream of the Bear Valley Road berm, the stream channel becomes indistinct, dissolving into an open water marsh. The stream channel remains indistinct through Olema Marsh until just upstream of Levee Road, where a row of willows and alders marks its course through the Levee Road culverts and County White House Pool park to Lagunitas Creek.

Like the Inverness Ridge tributaries draining the Olema Creek watershed, Bear Valley Creek is a perennial system. No long-term flow monitoring has been completed in the watershed. However, a water supply study completed by the USGS in the mid-1960’s does provide some estimates of late-summer creek baseflows or the amount of water in the creek once flooding from rains has ceased (Dale and Rantz 1966). This study indicates that, even though the Bear Valley Creek watershed is just over a quarter of the size of the Olema Creek watershed, summer baseflow rates (measured near Park Headquarters) are of a similar magnitude, ranging from 0.5-cfs during normal rainfall years to 0.25-cfs during dry year-types. The greater yield of Bear

Valley relative to Olema reflects the higher water-bearing properties of the deposits underlying the Inverness Ridge relative to the Franciscan complex material underlying ridges to the east of the San Andreas rift valley (KHE 2006a).

Construction of a road parallel to Bear Valley Creek to connect Point Reyes Peninsula with the town of Olema in the 1800s represented the first of many major infrastructure and management impacts that impacted the subwatershed (Table 7). During the 1800s, Bear Valley Creek was described as having numerous riffles and pools underneath a substantial riparian canopy. This fluvial system eventually flowed into Olema Marsh, which was then a large integrated tidal marsh complex with sinuous tidal sloughs (KHE 2006b). In 1892, a long, culverted berm was constructed across the mouth of Olema Marsh for Sir Francis Drake Boulevard or Levee Road. Following construction of Levee Road in the late 1800s- early 1900s, the creek was dammed by dairy ranchers in the 1920s. NMWD currently has a water right on Bear Valley Creek for diversion of 0.401 cfs between January 1 and December 31, but it is not currently used for water supply (C. DeGabriele, NMWD, *pers. comm*.). Based on a 1942 photo, this area appears marshy and heavily grazed, and there is little riparian vegetation until the creek approaches Olema Marsh. A number of culverted berms were built for Bear Valley Road and the ranch roads in the upper portion of the watershed, all of which affected hydraulic connectivity and sinuousity. The original road from Olema to the Point Reyes Peninsula was eventually replaced with Bear Valley Road and Sir Francis Drake Boulevard. Limantour Road was constructed after World War II. In the 1970s, the Seashore moved a portion of Bear Valley Creek channel for construction of the maintenance facility yard and buildings. By the early 1980s, maintenance dredging for flood control purposes had led to the middle and lower reaches of Bear Valley Creek becoming deeply incised, with the creek bottom roughly 6-8 feet below the floodplain terrace bank at the Seashore's maintenance yard (KHE 2006b).

In 1982, Bear Valley Creek changed dramatically as a result of the New Year's Day floods. Catastrophic debris flows originating from the unstable weathered granite of the Inverness Ridge flowed through tributaries into the mainstem of Bear Valley Creek, choking the former channel, scouring existing road/trail facilities, and turning the colluvial valley bottom into a sandy, braided stream channel with extensive woody debris jams that acted to temporary dam and pond waters within the channel. Storm clean-up resulted in some of the excavated sediment being placed in the floodplain and possibly on the northern edge of Olema Marsh adjacent to Levee Road (Table 7; KHE 2006b). The State Coastal Conservancy provided funding to Audubon Canyon Ranch in the 1980s for an enhancement project, which consisted principally of using drag-lines to create small, unvegetated ponds in Olema Marsh, some of which still persist today. During the 1998 El Nino events, similar small-scale landslides and hillslope failures were observed throughout the Bear Valley Creek watershed. Sediment deposition during the 1998 flood also precipitated a change in channel course for lower Bear Valley Creek from the west to the east side of Olema Marsh. Since 1982, the County of Marin has also diverted one of the larger drainages to Olema Marsh, Silver Hills, to run alongside Levee Road and flow out of the historic outlet on the west side of the marsh.

While Olema Marsh has been heavily impacted by road construction, long-term water level monitoring in Olema Marsh and lower Bear Valley Creek show that conveyance capacity of the Bear Valley Road culverts is still sufficient to pass most streamflows without problems such as backwater flooding (KHE 2006a). Culverts at Bear Valley Road consist of two 6-foot diameter culverts that have a conveyance capacity of 600 cfs (KHE 2006b). However, water levels in Olema Marsh are dramatically higher than the elevation of the downstream 6-foot by 7-foot box culvert at Levee Road, indicating water impoundment and poor hydraulic connectivity between Olema Marsh and downstream Lagunitas Creek (KHE 2006a). The minimum water surface elevation recorded during baseline studies (8.4-feet NAVD88) in Olema Marsh is almost 4-feet higher than the minimum or base water level elevation recorded immediately upstream of the Levee Road culvert (KHE 2006b).

Outflow appears to be limited by several factors (Table 7). As noted earlier, the 1998 storm caused Bear Valley Creek to migrate from a well-defined channel on the western side of the marsh to a more amorphous, ill-defined flow path on its eastern edge, and sedimentation essentially blocked off the western outlet (KHE 2006b). Blockage of the western outlet reduced the available surface area for potential flow conveyance from the marsh from 106 square feet to 42 square feet, which translates into a reduction in conveyance capacity from approximately 630 - 700 cfs to 410 cfs (KHE 2006a). A 5-year flood event produces approximately 490 cfs in Bear Valley Creek (G. Kamman, KHE, *pers. comm*.). In addition, outflow is also severely reduced by an approximately 315-linear-foot earthen berm hardened by heavy vegetation establishment on the east bank of lower Bear Valley Creek just upstream of Levee Road (KHE 2006b). Problems with conveyance of flows at Levee Road have caused backwater flooding that has increased water levels, as well as in lower Bear Valley Creek (KHE 2006a). Based on a comparison of water levels and culvert submergence conditions at Bear Valley Road in 1990 (Evans 1990) and 2005 (KHE 2006b), standing water levels during the summer appear to have increased approximately 6 feet since 1990, which predated the 1998 flood event and migration of the

Bear Valley Creek channel in Olema Marsh (KHE 2006b). Impoundment in Olema Marsh has also resulted in an increase in water surface levels in the Bear Valley Creek marsh directly upstream of Bear Valley Road. Water levels within Olema Marsh (and Bear Valley Creek Marsh) are predicted to continue to increase, which could have a considerable effect on the potential for flooding during storms of Levee and Bear Valley Roads, which are frequently flooded even during smaller storm events.

Tomasini Creek. The Tomasini Creek watershed is over 3.5-miles long, averages 0.75-miles wide, and has an estimated drainage area of 3.3-square miles (KHE 2006a). The upper two-thirds of the watershed consist of Franciscan complex bedrock; the lower third drains lands built on marine terrace deposits that underlie the Point Reyes Mesa (KHE 2006a; Figure 20). Upstream of Mesa Road in property owned by the county as an open space easement, the creek flows down a moderately sloped section of the Tomasini Creek valley in a shallowly entrenched, albeit well-defined channel through a broad riparian zone until it reaches the road, where backwater flooding from undersized culverts and an abrupt change in creek gradient has caused the creek to broaden and become marshy (Table 7). The creek enters the eastern side of the Project Area through a pair of 6-foot diameter circular steel culverts underneath Mesa Road. From there, the stream gradient flattens considerably, encouraging deposition of sediment and debris that has created a blockage that reduces hydraulic connectivity between upstream and downstream reaches.

Tomasini Creek is contained within a leveed channel along the eastern border of the Project Area to its outfall with Lagunitas Creek near Railroad Point or the north levee of the East Pasture (Table 7). This outfall consists of a 22-foot-wide concrete weir containing a line of four 3-foot-diameter circular culverts equipped with one-way tide gates on downstream ends (KHE 2006a). The Tomasini Creek levee was constructed sometime between 1955 and 1960 (KHE 2006a). This levee was constructed to divert Tomasini Creek out of its natural channel alignment, which meandered through the East Pasture. Review of available historic aerial photographs from 1942 and 1943 indicate that, prior to construction of the current levee, the Giacominis may have attempted to redirect Tomasini Creek in a southward direction along the base of the Mesa below the Giacomini Dairy Facility and through the Green Bridge County Park to an outfall point into Lagunitas Creek opposite Olema Creek (KHE 2006a). The historic outlet of Tomasini Creek into the former marsh floodplain is visible in the 1942 photograph as a sizeable alluvial fan (KHE 2006a).

No flow monitoring has been completed on Tomasini Creek. However, flow characteristics (if not totals) for this drainage are likely similar to those on Walker Creek in the northern portion of the Tomales Bay watershed (KHE 2006a). Based on USGS flow records for Walker Creek, winter runoff characteristics in the Tomasini watershed are probably flashy (i.e., very short lag time between rainfall and runoff) and likely similar in magnitude, per unit area, to those in the lower Lagunitas Creek watershed (KHE 2006a). The flashiness of this system is supported by the Giacominis, who attested to the propensity for Tomasini Creek to have high-intensity, short-duration storms that cause significant flooding, particularly in combination with high tides (KHE 2006a). The largest difference between this drainage and others in the Project Area is that summer baseflow rates are much lower per unit area (KHE 2006a). As with Walker Creek, Tomasini Creek does dry down during average and drier years in late fall (NPS, unpub. data), with sustained year-round flows only occurring during wet-year types. However, groundwater springs and seeps within the Point Reyes Mesa terrace deposits may contribute significantly to the creek base flow during summer and fall, maintaining perennial flow and brackish salinities, at least in downstream reaches (See Water Resources – Groundwater).

Similar to other creeks within the watershed, water is extracted from Tomasini Creek through at least three water rights agreements, primarily during the winter for off-creek storage (Table 7). One of these water rights, which covers storage of 12 acre-feet per year between October 1 and April 1, was transferred to the Park Service with purchase of the Martinelli Ranch. In addition, the creek may be negatively affected by the presence of the now-closed West Marin Landfill within its watershed: the landfill is apparently inundated on occasion by overbank flooding during high flows and may therefore potentially decrease downstream water and sediment quality (Table 7). This issue is discussed in greater detail under Soil Resources and Water Resources – Water Salinity and Quality.

Fish Hatchery Creek and Inverness Ridge Drainages. There are four small watersheds draining Inverness Ridge, which enter the Project Area between White House Pool and the North Levee (Figure 27). These drainages include (from south to north): Haggerty Gulch (1.7-square miles); Fish Hatchery Creek (0.9-square miles); the "Creek 2 or 1906 Drainage" (0.2-square miles); and the "Unnamed Tributary" (less than 0.1-square miles; KHE 2006a). Names for the latter two drainages came from a 1917 National Geodetic Survey map (KHE 2006a). All of these drainages are underlain by weathered granite, and each displays perennial flow and copious winter sediment production. On a per unit area basis, the amount of runoff from each of these small watersheds is similar to that for Bear Valley Creek (KHE 2006a).

All of these drainages are characterized by steep to extremely steep stream gradients as waters flow down ravines on the Inverness Ridge. Within the Project Area, the gradient abruptly flattens, representing active depositional fans. In 1899, Schofield noted that Fish Hatchery Creek was "at first fed by springs and (runs) through cool shady woods,….but on gaining the open valley," it runs through two miles of marshy lowlands. Flows currently enter the Project Area through culverts underneath Sir Francis Drake Boulevard (Table 7). Haggerty Gulch discharges directly into Lagunitas Creek at White House Pool through a 4-foot-diameter circular steel culvert (KHE 2006a; Figure 27), which appears to be at least contributing to some bank erosion and possible undercutting of the Sir Francis Drake Boulevard road base (Land People 2005). All other drainages flow into the West Pasture or private properties on the east side of Sir Francis Drake Boulevard.

Fish Hatchery Creek enters the Project Area on the north side of the Gradjanski property where it flows to the central portion of the West Pasture (Figure 27). The channel near Sir Francis Drake Boulevard has been frequently dredged to remove sediments deposited during storms by the Giacomini family (Table 7). The channel passes through the West Pasture north levee in a pair of recently replaced 3-foot-diameter circular steel culverts equipped with modified tidegates on the downstream side (Table 7). These flap gates are propped open slightly to permit limited two-way exchange between undiked portion of Fish Hatchery Creek and the West Pasture. As with Lagunitas and Tomasini Creeks, water is extracted from Fish Hatchery Creek through at least four water rights agreements, primarily through direct diversions. NMWD has a water right for 0.666 cfs between January 1 and December 1, and the Giacomini family has a water right for 0.5 cfs between April 1 and December 1.

After crossing under Sir Francis Drake Boulevard, the "Creek 2 or 1906 Drainage" channel crosses through the Lucchesi property and discharges into the West Pasture (Figure 27; Table 7). After flowing through a concrete box culvert, the creek makes a roughly 90 degree turn that funnels flow directly into the south end of the West Pasture freshwater marsh. As with Fish Hatchery Creek, the 1906 drainage requires near-annual maintenance to remove accumulated sediment and reduce flood hazards to adjacent properties. The chronic flooding at these properties is driven by channel infilling with granitic alluvium eroded from the Inverness Ridge with subsequent increase in water levels during storm events due to aggradation of the channel bed (KHE 2006a). Flooding impacts are discussed more under Public Health and Safety – Flooding. The 1906 Drainage flows into central southern portion of the marsh, after which it appears that flow largely follows topographic gradients into the depressional basin in the lower-elevation central and eastern portions of the marsh. This depressional basin has formed in response to higher elevations to the west (base of Inverness Ridge), east (West Pasture), and south (1906 Drainage alluvial fan).

The "Unnamed Drainage" has been observed flowing from a culvert in Sir Francis Drake Boulevard into a densely wooded riparian area on the east side of Sir Francis Drake Boulevard and then discharging into a remnant road-side drainage ditch (Figure 27). The water then flows north into Fish Hatchery Creek, just upstream of the north levee culverts. The subtle swale that constitutes this remnant roadside ditch appears to be the dominant water conveyance feature on the west side of the West Pasture freshwater marsh (KHE 2006a).

Another small drainage occurs in the southern portion of the West Pasture (Figure 27). This seasonal creek is also culverted underneath Sir Francis Drake Boulevard and has been ditched to connect with an existing low spot marked by a stand of arroyo willow (*Salix lasiolepis*) near the center of the pasture).

Interior Drainage Ditches and Remnant Slough Features. In the West Pasture, a small drainage appears at the southeastern corner of the Gradjanski property that flows eastward before turning north parallel to Sir Francis Drake Boulevard and eventually connecting with Fish Hatchery Creek near the north levee culvert. As was discussed earlier, this drainage, called the West Pasture Old Slough (Figure 27), appears to be the remnant of a historic tidal slough that has been ditched by the Giacomini family in its most upstream reaches to channel surface run-off from seasonal seeps or springs on the Gradjanski property. The southern portion of the Gradjanski property near this ditch is extremely marshy and appears to be wet for most of the year, although surface flows are only present in the most upstream portion of the slough for one to two months after spring rains end, typically drying up by March or April of each year (Parsons, *in prep*.).

The East Pasture contains a much more elaborate and extensive drainage ditch network to direct surface run-off and deliver and drain irrigation waters applied to the pastures (Figure 27). Historically, water was diverted from Lagunitas Creek near the upstream end of the East Pasture in the summer after installation of the earthen dam. Currently, the Giacominis are receiving irrigation waters from NMWD's Downey Well, with the waters being piped to the Ranch. Some of the drainage ditches in the East Pasture appear to be former slough channels that have been straightened, with the exception of the northern portion of the largest drainage channel, called the East Pasture Old Slough, which still retains a prominent relict meander. There are two discharge points for drainage ditch waters: a pump-house on the east bank of Lagunitas Creek and three 4-foot-diameter circular steel culverts equipped with one-way tidegates at the northern end of the East Pasture Old Slough. While relatively high salinities in the ponded area adjacent to the tidegates would suggest that these gates are leaky, floodwaters often pond in the northern portion of the East Pasture longer than the West Pasture, which may indicate that these gates and the culvert are not effectively allowing waters to move out.

Irrigation waters are spray-irrigated in a large percentage of the northern portion of the East Pasture, with flood irrigation methods used for the southernmost pastures. Some pastures do not appear to be actively irrigated during the summer, probably because soil salinities are consistently high enough even with irrigation to preclude establishment and maintenance of pasture. In the past, the Giacominis used some of the drainage ditch waters to artificially flood the New Duck Pond and create conditions conducive to use by waterfowl. In addition to irrigation on the East Pasture, the standard dairy practice also includes spray irrigation of liquid waste from the manure ponds. The waste spraying occurs in the summer months within the East Pasture.

Groundwater

Tomales Bay. In addition to tidal and fluvial surface water, the other major hydrologic source to the Project Area is groundwater. According to Oberdorfer et al. (1990), groundwater flow accounts for less than 1 percent of the freshwater in the watershed, but it undeniably influences the hydrology and biology of this and other coastal California watersheds. Within the Tomales Bay watershed, groundwater substantially increases hydrologic complexity within wetland ecosystems by replacing the traditional upland to wetland cross-sectional transition common of most salt marsh systems with a freshwater to saltwater transition. Within many Tomales Bay subwatersheds, salt marshes are fringed with freshwater, brackish marsh, or riparian habitat due to the influence of seeps and springs along most of their perimeter (Parsons et al. 2004). Seeps and springs form the headwaters for many of the small drainages that flow to the Bay (Parsons et al. 2004).

The prevalence of these hydrologic sources within the Point Reyes area relates directly to the geologic complexity of this unstable region, with lateral and vertical movement along the San Andreas Fault fracturing basement rock and enabling underground aquifers to connect with the ground surface. However, certainly in more developed areas, groundwater and seep flow has probably been augmented to some degree by leaking septic systems, as many of the systems within Tomales Bay are antiquated and in need of repair or modernization (TBWC 2002).

East Pasture. Within the East Pasture, groundwater generally flows from south to north on a northwest gradient, largely following the northwest trend of the rift valley that probably imparts a strong parallel groundwater flow pattern similar to other fault-derived flow paths (KHE 2006a). In general, the groundwater gradient mimics the topography of the East Pasture, except in the very northern portion where the flatness of the pasture disconnects the groundwater table from surface topography (KHE 2006a). The lowest portion of the East Pasture is actually in the northeastern corner.

Groundwater was not included in the hydrodynamic model developed by KHE, however, groundwater depths were monitored regularly through shallow groundwater monitoring wells. These data show that a very shallow groundwater table exists throughout most or all of the year (KHE 2006a), with water depths being closer to the surface in the northern, lower elevation portions of the East Pasture. This groundwater table may originate from water-bearing alluvial deposits or layers within the Point Reyes Mesa (KHE 2006a), the adjacent coastal marine terrace formation that consists of non-marine and marine sand, gravel, silt and clay layers (Galloway, 1977; Clark and Brabb, 1997). Past development of small-scale groundwater wells for private use on the Point Reyes Mesa for residents has uncovered several water-bearing layers within this terrace, one of which is at approximately Mean Sea Level or roughly at the same elevation as the northern portion of the East Pasture (G. Ferrando, Point Reyes resident, *pers. comm. in* KHE 2006a). The depth of this groundwater table, as well as the potential for presence of an aquifer beneath the East Pasture, is constrained by the stratigraphy of the East Pasture, which is underlain by deep estuarine clays of low organic content, low permeability, and low groundwater storage capacity that act as aquitards or barriers to groundwater exchange (KHE 2006a).

This factor strongly argues against the possibility of freshwater aquifer of any significant thickness, lateral extent, or storage capacity beneath the East Pasture (KHE 2006a).

Groundwater depths are not always consistent with the topography. The emergent of hillside springs or seep flow from the base of the Point Reyes Mesa contributes another layer of hydrologic complexity (Figure 27). These seeps and springs have promoted establishment of dense riparian scrub and marshy areas on the edges of the Mesa or even on its slopes, which are visible in 1942 photographs of the Project Area. The Giacominis have dredged ditches at the base of the Mesa in many areas to reduce flooding of pastures from groundwater. The source of these seeps and springs is undoubtedly one of the shallower water-bearing alluvial layers that have been documented by groundwater well development in the Point Reyes Mesa terrace. Natural groundwater influences have probably been augmented to some degree by septic systems from the relatively densely populated developments on the top of the Point Reyes Mesa and, in some areas, by non-point source run-off from the town of Point Reyes Station. The relative contribution of septic influences to groundwater cannot be determined, but some limited water testing by the Seashore did detect Methlyene-Blue Active Substances (MBAS) in low concentrations at several locations around the perimeter: MBAS is a constituent of surfactant detergents and a fairly reliable indicator of septic or sewer influence (NPS, unpub. data). Interestingly, much of the West Pasture freshwater marsh appears almost to be completely tidal marsh in 1942, when this area was not diked, which potentially suggests that there has been a substantial increase in localized freshwater flow in this particular area of the West Pasture.

Some of the most evident seeps and springs in the East Pasture and vicinity occur on 1) the riparian habitat and seasonal wetland on eastern perimeter of Green Bridge County Park; 2) seasonally flooded pasture and riparian scrub on the southern slopes of the dairy mesa facility; and 3) seasonally flooded pasture, freshwater marsh ditch, and riparian-marsh scrub on the northern slope of the dairy mesa facility. The most and noticeable area with seeps and hillside springs is the section of the Point Reyes Mesa north of the Giacomini Hunt Lodge and south of Railroad Point. Surface run-off of hillside springs, combined potentially with groundwater emergence at its base, have not only created an extensive riparian scrub or Mesic Coastal Scrub community (see Vegetation Resources) on the face of the “bluff,” as it is known, but appears to contribute to some degree to base flow within Tomasini Creek. Most importantly, groundwater inflow may buffer increased salinities within Tomasini Creek, which has become tidal again since failure of the tidegate, and thereby benefit the federally endangered tidewater goby, a brackish water species.

While the groundwater table underlying the Point Reyes Mesa would be considered “fresh,” groundwater within the East and West Pastures is saline, with salinities ranging from 2 ppt (brackish) to as high as 40 ppt (hypersaline; NPS, unpub. data). Even the highest elevation area of the East Pasture that appears to be strongly influenced by groundwater from the Mesa had salinities as high as 5-6 ppt, which is brackish (NPS, unpub. data). Research conducted on the groundwater aquifers within the Point Reyes Station area have documented elevated chlorides, an indicator of salinity, in groundwater, even during the winter (Questa Engineering Corp. 2001: Affordable Housing). However, groundwater within the East Pasture displayed an ionic composition more characteristic of marine systems than that of the local aquifers or that would be expected from the presence of cattle and other agricultural practices such as manure spreading (NPS, unpub. data). Salts observed within groundwater, then, appear to be marine salts that were trapped within sediment during deposition prior to diking of the pastures (KHE 2006a). These salts are bound tightly to clay sediments and apparently leach into the groundwater table when it is contact with the clays. As noted earlier, early attempts by the Giacominis to use groundwater from two wells installed at the southeast portion of the East Pasture for irrigation failed due to poor water quality (SWRCB 1995).

As was noted earlier, limited portions of the East Pasture bordering Lagunitas Creek appear to have a hydraulic groundwater connection with the creek that causes shallow groundwater within these portions of the pasture to move up and down to some degree with tidal cycles (KHE 2006a). Although soils in these areas contain very porous coarse alluvium, there does not appear to be movement of water through the soils between undiked and diked areas, but rather that pressure from the tides creates a corresponding hydraulic pressure on the shallow groundwater table within the pasture (KHE 2006a).

West Pasture. Although limited monitoring was conducted in the West Pasture, as with the East Pasture, the general groundwater gradient in the West Pasture appears to run from south to north, again following the general topography and creating higher water levels within the very northern portions of the pasture. This groundwater gradient is overlain by the west to east groundwater gradient established by seeps, springs, and small drainages flowing off or emerging from the base of the Inverness Ridge (Figure 27).

The influence of seeps and springs is more pervasive along the West Pasture perimeter than the East Pasture one, as evidenced by the thin strip of arroyo willows that fringe the pasture along almost its entire length adjacent to Sir Francis Drake Boulevard. Flooding duration varies depending upon location along the perimeter, with some areas saturated to the soil surface for a brief time, while others are wet either permanently or seasonally throughout the winter and spring. There are at least four sizeable areas that are defined by groundwater influence. Two are south of the Gradjanski property and flood for an extended period during the winter and spring. The third occurs between the Gradjanski and Kostelic residences near Fish Hatchery and is flooded or saturated for an extended period. The fourth is the West Pasture freshwater marsh, which floods from groundwater as well as from creeks (1906 Drainage, Unnamed Drainage) and occasionally tidal incursions. As with the creeks, groundwater flow to the marsh appears to be perennial, with much of the flow at least initially routed into an old drainage ditch alongside Sir Francis Drake Boulevard that has not been maintained for some time.

Stormwater Run-Off Sources for Project Area

Another source of hydrology for the Project Area is non-point source discharge run-off from adjacent communities and developments (Figure 27). The Project Area is bordered by two towns and at least three developed areas – Point Reyes Station, Levee Road, and Inverness Park. While some non-point discharge probably occurs from roadside run-off on Sir Francis Drake Boulevard and Levee Road flowing into the West Pasture and Olema Marsh, respectively, larger non-point source discharge occurs from at least three locations in the East Pasture and Tomasini Creek. One shallow ditch conveys run-off from the southern portion of the town through the Green Bridge County Park to a discharge location on Lagunitas Creek just upstream of the Giacomini Ranch. Another ditch conveys run-off from the central and western portions of town to the north-facing portion of the Dairy Mesa facility, where run-off flows down a vegetated swale into the Tomasini Triangle pasture at the eastern edge of the East Pasture. This ditch runs directly next to one of the unvegetated feedlots for young heifers or cattle run by the Giacomini Ranch and probably receives run-off from this lot during storm events. A third ditch parallels Mesa Road in a vacant lot west of the road and eventually joins with Tomasini Creek just after it flows underneath Mesa Road. Flow patterns for these discharges are unknown, but almost all of them are dry by summer, with the possible exception of the one at the Green Bridge County park, which has flow perennially. Groundwater flow from the bottom of the Point Reyes Mesa appears to be channeled into this ditch, as well, possibly explaining the extension of flows beyond the winter and spring rainy season.

Water Resources – Floodplains

As noted earlier, one of the more important hydrologic functions that wetlands and streams play is floodwater retention and dissipation of flood flow energy. This function results from the ability of creeks and bays to be able to move onto their floodplains during periods of high water. Many of these floodplains are vegetated, which helps to slow down flood waters, as well, by a providing a source of “roughness” or resistance. This dissipation of flood flow energy and retention of floodwaters not only benefits humans, but wildlife. This section specifically addresses hydrologic processes related to flooding and access to floodplains within the Project Area. Detailed information on flooding and floodwater retention capabilities of floodplains related to human safety and protection of property is discussed later in this chapter.

One of the more important hydrologic functions that wetlands and streams play is floodwater retention and dissipation of flood flow energy. This function results from the ability of creeks and bays to be able to move onto their floodplains during periods of high water.

For optimal performance of these functions, wetlands and streams should be physically connected to their floodplains and have an intact riparian corridor. The largest creek within the Project Area is Lagunitas Creek, whose floodplains represent almost the entire 550-acre Giacomini Ranch property. As noted earlier, Lagunitas Creek has been subject to a number of hydrologic alterations that could affect flooding. Construction of five dams in the upper watershed has undoubtedly altered flood flow structure. Typically, dams reduce the frequency and duration of instantaneous peak flows, while increasing the duration of bankfull or ordinary high water flows (Fenner et al. 1985, Stromberg and Patten 1990, Johnson 1992, 1994, 1998, Friedman et al. 1998). Within the Lagunitas Creek watershed, the dams are operated specifically for water supply. Except for the mandated flow releases (SWRCB Decision 95-17), the reservoirs are operated to fill, and then spill. In general this means that drainage area during earlier events is limited to the undammed portions of the watershed. Once the reservoirs are full, they pass peak flows through. The effect of the dams on flooding is specifically tied to the timing of the storm event. If the event occurs early in the season, when reservoirs are filling, flooding would be dramatically reduced. If the event occurs after the reservoirs are full, the dams would not change flooding scenarios. In all cases, however, the dams do change the pattern of sediment supply and transport through the watershed. During dry years, the dams reduce the overall level of downstream flooding through increased reservoir retention of flood flows.

In the Project Area, Lagunitas Creek has been disconnected from its floodplains by the 8- to 17-foot levees that have been constructed along its perimeter, which has created a strongly to moderately entrenched creek along this reach and reduces the ability of the creek to connect with its floodplain. During 2-year flood events -- or floods of a magnitude that occur, on average, every 2 years or some recurrence interval greater than that – levees are high enough to preclude the East Pasture from being flooded by Lagunitas Creek. Hydraulic modeling results show that, during 2-year flood events, inundation area totals only 2 acres, and standing water volume totals only 2 acre-feet, most of which comes probably from precipitation and surface run-off (KHE 2006a). Flood recurrence was modeled using extreme flooding conditions, combining both high flood flows and extreme tides (6.0 feet) such as occurred during the 1982 flood (KHE 2006a). In the West Pasture, inundated area (76 acres) and standing water volumes (62 acre-feet) are larger than the East Pasture even under conditions when levees are not overtopped by Lagunitas Creek (<12.5 year flood event), because of surface flows from Fish Hatchery Creek and other small drainages (KHE 2006a). In Olema Marsh, standing inundation volume totals 202 acre-feet during a 2-year event, with most of that water coming from Bear Valley Creek, because poor hydraulic connectivity and the large standing water volume in the marsh greatly reduce the potential of Olema Marsh to provide off-channel floodwater storage for Lagunitas Creek (KHE 2006a).

During 2-year flood events, then, almost all of Lagunitas Creek flood flows remain in the channel, greatly increasing flood stage or the vertical height of flood flows. Hydraulic modeling suggests that, under a 2-year event, peak flood flows in the Project Area could reach as high as 8.2 feet, because of the lack of floodplain storage (KHE 2006a). The cumulative volume of water that could move through the Project Area in Lagunitas Creek under a 2-year event totals approximately 437.8 million cubic feet of water based on hydraulic modeling estimates (KHE 2006a). The lack of floodplain storage not only increases the stage and volume of water in Lagunitas Creek under 2-year events, but exacerbates the erosion potential of flooding, because floodplains dissipate the erosive energy of flood flows. Streamside riparian vegetation can reduce flood flow energy, but 60 to 70 years of levee maintenance has limited the amount of riparian growth, at least along the Giacomini Ranch levees.

Despite levees, overbank flooding does periodically occur (KHE 2006a). Hydraulic modeling indicates that the East Pasture creek bank upstream of White House Pool near the old summer dam location is overtopped by approximately a 3.5-year flood or greater (KHE 2006a). During 5-year flood events, inundated area and standing water volume increases greatly, with acreage increasing from 2 to 249 acres and standing water volume increases from 2 to 611 acre-feet (KHE 2006a). Under successively larger flood flows, inundation area steadily increases, with standing water volume increasing to 2,818 acre-feet in the East Pasture and 450 acre-feet in the West Pasture during a 100-year flood event or flood with a similar magnitude to the 1982 event (KHE 2006a). Comparatively, standing water volume in the 66 acres of Olema Marsh that are inundated during a 100-year flood event averages approximately 544 acre-feet (KHE 2006a). During 100-year events, flood stage or vertical height of flood flows in Lagunitas Creek is only slightly higher (~ 12.5 feet) than under a 2-year event (8.2 feet), because flood flows are being shunted into the East and West Pastures, thereby relieving flood pressure in the creek itself (KHE 2006a). Based on computer simulations, water levels could reach as high as 13.1 feet in the East Pasture and 9.8 feet in the West Pasture during 100-year flood events (KHE 2006a). From modeling 100-year flows, it is apparent that the West Pasture can absorb only a fraction of the floodwaters that move through the East Pasture (~3.2 percent) and Lagunitas Creek (~1.4 percent; KHE 2006a).

During flood events such as these in which overtopping occurs, water levels within Lagunitas Creek build in vertical height or stage until they exceed the height of the levees, at which point they overtop and flood into the East and West Pastures. Once waters flow into the leveed pastures, the pastures fill rapidly to a maximum standing water volume, where floodwater persists for some time as they slowly drain through the only outlets, which are the concrete spillway and tidegate/culvert (West Pasture only). The southern portions of the East and West Pasture drain quickly, but, during larger storms, floodwaters can remain ponded within the northern portions of the pastures for more than a week, because elevations are lower in these areas than the concrete spillways.

The Levee Road Lagunitas Creek bank floods, on average, during 3-year or greater flood flows (KHE 2006a). While the difference may not seem dramatic, the section of the East Pasture that was modeled is one of the lower elevations areas along the south bank (10-11 feet). Upstream of this location, the levee resumes, and the crest height is 14- to 17-feet, with overbank flood recurrence intervals correspondingly increasing in this area to between 50- and 100-year storm events (KHE 2006a). These results suggest that the height of the Giacomini Ranch East Pasture levee and creek bank effectively places higher flood pressure on Levee Road and the 15- to 20 homes built along the creek's edge (KHE 2006a).

Downstream of White House Pool, flood frequency drops, probably because the creek widens, thereby decreasing stage height or height of flood flows relative to the narrow creek section upstream of White House Pool for floods with the same frequency. While the East Pasture levee downstream of the cattle crossing location is lower in elevation than the one near the old summer dam, flood flows only overtop the levee in this area during a 7-year event (KHE 2006a). The West Pasture levee is also lower in elevation than the East Pasture one, ranging from only 10- to 12-feet high, and, yet, the West Pasture is only flooded by Lagunitas Creek when flood events are quite large (≥12.5-year flood recurrence interval; KHE 2006a).

Lagunitas Creek's floodplains overlap considerably with those of the two other primary tributaries to the pastures – Fish Hatchery and Tomasini Creeks. With the exception of some limited dredging, Fish Hatchery Creek is a very shallow system with relatively intact floodplains. Floodplains are defined by the higher elevation perimeters of the West Pasture along its western and eastern edges. Conversely, Tomasini Creek has been entirely disconnected from its floodplain through construction of a berm. No information is available on how often this creek might overtop its berm, which varies in height near the Giacomini Hunt Lodge from 8 to 12 feet NAVD88, but overtopping events were not observed during 2001-2005. In late 2005-2006, a winter storm-extreme high tide event in January estimated as an approximately 30-year event appears to have breached and overtopped the berms and caused some erosion near the Giacomini Hunt Lodge. According to the Giacominis, the section of levee near the Giacomini Hunt Lodge is the most susceptible to erosion and breaching by Tomasini Creek (KHE 2006a). Currently, Tomasini Creek's active floodplain is restricted to the small floodplain terrace benches on either side of the creek, one of which is the historic railroad grade. Historically, floodplains for this meandering creek probably encompassed a relatively large portion of the East Pasture.

Floodplains for the other creeks and drainages in the West Pasture are relatively small, with the possible exception of the 1906 Drainage, which has a very narrow, confined floodplain through and just downstream of the Lucchesi property until it flows into the West Pasture freshwater marsh. The 1906 Drainage is excavated annually just downstream of the Lucchesi residence for flood minimization purposes.

Floodplains for the lower portion of Bear Valley Creek are defined by Bear Valley Road, which runs along its eastern perimeter, and the elevated floodplain terrace created from deposition of granitic alluvium on its western perimeter. The lower reach of the creek has no defined channel planform or "bed and bank," thereby allowing flood flows to spread across a moderately wide section of the floodplain. Downstream of Bear Valley Road, the creek flows into Olema Marsh, with most of the flows hugging the eastern perimeter. However, the lack of a well defined channel and bank within this section enables the creek to use a large portion of the marsh as a floodplain.

Water Resources - Sediment Transport Dynamics

One of the most important processes for bays and creeks involves movement of sediment from upstream source watersheds to downstream water bodies, such as Tomales Bay or even the Pacific Ocean. This process of moving sediment does not take place instantaneously, but rather over a longer period of time, with large and small-grained material such as gravel, sands, silts, and clays being moved incrementally downstream during different storm events. Through this process, the shape or geomorphology of creek channels is formed. Once sediment finally reaches tidally influenced downstream water bodies, a new type of transport process takes place. Sands from the ocean and river-borne sediments, particularly fines, are continually resuspended by tides and redistributed within estuaries, helping to build sandbars, mudflats, and fringing marshes.

Fluvial or Creek-Dominated Processes

While large flooding events are often accompanied by huge inputs of sediment to downstream water bodies, more frequently occurring flood events, even as frequent as annual or ordinary high water flows, usually move more sediment and have a greater influence on channel shape (Leopold 1994). Reaches of channel tend to go through periods where they either accrete or lose more sediment, however, over time, the aggradation and erosional processes remain in balance in undisturbed natural systems. Should natural catastrophic events change sediment loads, the system will move toward what might be called a new dynamic equilibrium state, ultimately coming to balance sediment inputs and outputs, although the channel may assume a new form or shape.

Anthropogenic disturbances can create discontinuities in the sediment transport process that can tilt the equilibrium scale towards either net aggradation or erosion and radically change the shape or form of the channel. Dams can drastically decrease the amount of sediment or gravel available for downstream recruitment. Areas in which no sediment movement or aggradation is occurring often have what is called “armored” or hardened gravel bars, signifying that material is not depositing or moving downstream. Conversely, areas in which the equilibrium is tilted toward aggradation often have conversion of subtidal or unvegetated intertidal habitats to vegetated ones. One of the most vivid examples of this is the conversion of southern Tomales Bay from a low-energy subtidal and low intertidal system primarily shaped by redistribution of fine-grained clays and silts from Tomales Bay to a fluvial-dominated deltaic system composed of large-grained sands, small gravel, and fines. The massive influx of sediment due to logging and other disturbances associated with development of the upstream watershed tilted the sediment equation from transport to aggradation, with rapid expansion of the intertidal delta into Tomales Bay. It has been estimated that the peak sedimentation period between 1860s and 1910 resulted in deposition of almost 5 vertical feet of sediment (PWA et al. 1993) and 250 -300 acres of new intertidal marsh in very southern portion of Tomales Bay, principally the Giacomini Ranch and area directly north of the Ranch.

During storm events, creeks are moving large or coarse-grained sediment (cobble, gravel, sand, and even boulders), as well as fine sediment (clays, silt, finer sands). Much of the coarse-grained material is deposited within the channels in gravel bars or immediately adjacent to the channel, sometimes forming alluvial or natural levees along the creek channel. Fine sediment typically deposits further from the stream channel through overbank flooding onto floodplains, although changes in channel morphology such as a sudden flattening of the creek gradient or slope, substantial widening of the creek channel, or transition from creek to a large open water body such as a bay can cause fine sediment to deposit within the stream channel itself. Gravel bars are depositional features within creek channels; on floodplains, sediment transport in creeks often manifests as alluvial fans or very large, rounded hills that occur in areas where there are sharp transitions between steep slopes and flat floodplains.

Within many alluvial or classic riverine systems, certain discharge or flow events are believed to perform the most work over the long-term in terms of sediment transport (Wolman and Miller 1960). The dominant discharge is often linked to intermediate streamflow or discharge events, which correspond to “bankfull flow” or flood events that occur every 1- 3 years or very 1.5- 2 years on average. However, there are systems in which the dominant discharge appears to be the largest flood on record such as the Santa Clara River (Stillwater Sciences 2005).

Estuarine Sediment Transport Processes

Within bays and estuaries, sediment is stored within mudflats, sand bars, and shoals or shallows. Storage within estuaries represents a very dynamic process, with frequent remobilization of sediments, particularly fines, from these storage "reservoirs" through resuspension by tides, storms, and wind mixing. These sediments are redistributed to marshplains, mudflats, and channels of the bay or even eventually exported to the ocean. Most of this sediment comes from the surrounding watershed, but sand moved by longshore sediment transport along the Point Reyes coast also moves into the bay to be redistributed by wind-generated waves (PWA 2005). As discussed earlier, construction of dams within the watershed appears to have dramatically reduced watershed sediment contributions to Tomales Bay (Rooney and Smith 1999), increasing the importance of resuspension to sedimentation patterns within Tomales Bay. Construction of dams in the Sacramento-San Joaquin watershed has also dramatically reduced the Central Valley contribution to the San Francisco Bay sediment budget, potentially accounting for large erosional losses in shallow areas in San Pablo and Suisun Bays observed between 1942 and 1990 (Jaffe et al. 1996, 2001 in McKee et al. 2002).

Estuarine circulation patterns largely dictate the pattern of sediment deposition within estuaries, particularly deposition of suspended or fine sediments. As with fluvial sediment transport processes, bathymetry and currents can exert tremendous influence on where suspended is resuspended and where it is deposited. However, estuarine areas are unique in that sediment transport and deposition processes can also be influenced by salinity. Bathymetry, currents, and salinity, either in combination or separately, appear to drive formation of concentrated zones of sediment deposition, which have been referred to as Estuarine Turbidity Maximum (ETM). During recent decades, extensive research has been conducted into this phenomenon, because of its implications for aquatic organism diversity and trapping of sediments, nutrients, and contaminants (Peterson et al. 1975; Arthur and Ball 1979; Kimmerer et al. 1998; Columbia River Estuary Turbidity Maxima (CRETM) 2001). Classically, ETM was linked to the Null Zone observed in transitional regions of estuaries with classic estuarine or gravitational circulation (e.g., strong stratification of fresh and tidal flows) near the landward boundary of tidal influence, which often occurs around 2 ppt (Postma and Kalle 1955; Festa and Hansen 1976; Festa and Hansen 1978); Peterson et al. 1975 *in* Kimmerer 2004). In these zones, sediment resuspended by strong tidal currents moving along the channel bottom and sediments carried by river or creek flow converge and are trapped by the upward moving current created by stratification at the landward extent of tidal influence, greatly increasing water turbidity and eventual sediment deposition on the channel bottom.

In recent years, physical controls other than the Null Zone have been linked to ETM, including abrupt changes in bathymetry or shoaling (Schoellhammer 2001), ebb and flood tidal currents in river mouths (Ganju et al. 2004), and redistribution of dissolved and particulate fractions in intermediate rather than low salinity reaches (Rasheed 1997). In addition to the effect that salinity has on stratification of estuarine waters and longitudinal gradients and currents, salinity can also play a direct role in determining patterns of sediment deposition through flocculation or aggregation of river-borne sediment particles caused by the increased electrostatic charge present at the landward edge of the "salt wedge" (Arthur and Ball 1979).

Sediment Transport Dynamics within Tomales Bay

For the Bay as a whole, the trend towards net aggradation continues, although construction of dams apparently caused deposition rates to drop substantially after the 1950s (TBWC 2002). Comparisons were made between 1861 and 1994 using hydrographic charts with corrections made for changing sea levels (Rooney and Smith 1999). These calculations showed a bay-wide average infilling rate of 0.2 inches/year, which is equivalent to a watershed erosion rate of approximately 80,000 tons per year (Rooney and Smith 1999).

Between 1861 and 1931, sedimentation accumulation rates within Tomales Bay averaged 94 tons per square kilometer per year, increasing to 357 tons per square kilometer per year between 1931 and 1957 and decreasing to 101 tons per square kilometer per year between 1957 and 1994 (Rooney and Smith 1999). These sedimentation patterns contrast somewhat with findings from the PWA et al. (1993) study of southern Tomales Bay and delta expansion, which pointed to the 1861-1931 period as having the highest sedimentation rates. Rooney and Smith (1999) note, however, that sediment yield in the Bay is not necessarily synonymous with erosion and that there can be "decades long delay between maximum level of soil surface disruption and maximum sediment deposition." During these decades, sediment is typically stored in streambeds, gradually moving towards the Bay through episodic resuspension during storms. Another storage reservoir for sediment is stream deltas such as Lagunitas Creek: "A similar delay was found between initial deposition of sediment at stream deltas and subsequent redistribution other areas of the Bay more geographically remote from deltas" (Rooney and Smith 1999).

While watershed sediment contribution has decreased in the last 50 years, Tomales Bay continues to become shallower through sediment inputs. In addition, colonization – or re-colonization – by native Pacific cordgrass (*Spartina foliosa*) appears to be causing a conversion in some areas of shallow intertidal mudflat to vegetated marsh. The present sedimentation rate in the bay, based on both bathymetric changes since 1957 and sediment yield measurements, has been about 0.04 to 0.08 inches/year (Smith and Hollibaugh 1998).

The dynamics of Null Zones or ETM have not been specifically investigated on a system-wide basis in Tomales Bay, but ETM may exist at the mouth of Lagunitas, Walker, and other tributaries to Tomales Bay that undoubtedly has many of the same benefits for biota documented in San Francisco Bay. The three-dimensional models developed recently for Tomales Bay would be invaluable in evaluating transport and depositional processes such as Null Zones and ETMs throughout the system, particularly as it could strongly bear on the fate of suspended sediment and associated nutrients, pathogens, and contaminants.

Sediment Transport Dynamics within the Project Area

Lagunitas Creek. Construction during the 1950s of the five dams within the Lagunitas Creek watershed, which controls 70 percent of the runoff for this subwatershed, has obviously greatly affected sediment dynamics within this system. MMWD studies conducted in 1979-1980 concluded that total suspended sediment delivery from Lagunitas Creek to the Project Area and vicinity averaged 34,300 tons per water year and 2,140 tons per water year of bedload or coarse sediment as calculated at the Point Reyes stream gage (H. Esmaili and Associates 1980). Annual bedload and suspended sediment transport totals actually decreased at the Point Reyes stream gage relative to the reach immediately upstream at the old Tocaloma Bridge, suggesting that increased channel storage or bank deposition was occurring in what was then – and probably still is now -- an aggrading reach or portion of the stream (H. Esmaili & Associates 1980). Many low-gradient or flatter reaches of creeks in coastal California undergo periods of net deposition during periods of high run-off followed by removal or net erosion during normal run-off conditions (H. Esmaili & Associates 1980). While the subwatershed of its largest tributary, Olema Creek, is less than a fifth the size of Lagunitas, Olema contributed significantly more suspended and bedload sediment to Tomales Bay -- 68,300 tons and 20,800 tons per year, respectively (H. Esmaili & Associates 1980). Higher sediment transport rates for Olema Creek were attributed to possibly climatic change, grazing, or other land use factors (H. Esmaili & Associates 1980), while work conducted in the late 1980s (Questa Engineering 1990) also identified differences in geology and the fact that Olema Creek flows along the active San Andreas Fault Zone.

While sediment transport generally increases with stream discharge or the size of the flood event, some streams have a diminishing rate of increasing suspended sediment transport at higher flows (Leopold 1994, Esmaili & Associates 1980). As noted earlier, more frequently occurring floods known as the "dominant discharge," that occur even as frequently as annually or during ordinary high water flows, usually move more sediment and have a greater influence on channel shape (Leopold 1994). Sediment studies conducted by H. Esmaili & Associates (1980) in 1979-1980 suggested that the rate of sediment transport in the lower sections of Lagunitas Creek just upstream of the Project Area begins to decrease during relatively small flood events (~1-year flood event), but that sediment load continues to increase through at least approximately the 7.5-year flood event and probably greater. Stream rating curves developed for Lagunitas Creek at the Point Reyes gage based on 1979-1980 data suggest that, at least during the early 1980s, a 2-year flood event with flow of 3,515 cfs would move a considerable amount of suspended sediment -- approximately 10,000 tons per day – but substantially less bedload material, only 170 tons per day (H. Esmaili & Associates 1980). None of the suspended material would have been deposited on floodplains because of the levees and/or lack of hydrologic connectivity.

While sediment transport patterns appear to have changed substantially in Olema Creek since the parks purchased portions of the watershed, land use factors affecting sedimentation rates in Lagunitas Creek would not appear to have changed substantially since construction of the dams in the 1950s. Within the Lagunitas Creek watershed, the dams would appear to exert the most control over sedimentation rates and patterns. Because dams tightly regulate some of the smaller flood flow events and their sediment loads, the highest rates of sedimentation in this subwatershed may now come with catastrophic flooding just as is seen currently in the Santa Clara River (PWA et al. 1993, Stillwater Sciences 2005). The 1982 flood caused deposition of 160 acre-feet of sediment on the Lagunitas and Walker Creek alluvial deltas (Anima et al. 1983 *in* PWA et al. 1993). The 1979-1980 study, however, demonstrates that there are still substantial sediment contributions from unregulated tributaries and their watersheds, even with the dams (H. Esmaili & Associates 1980). Current trends in the upper portions of the Lagunitas Creek watershed have not been formally studied, but several researchers have reported problems with “fining” or excessive deposition of fine sediments such as clays and silts relative to coarse materials such as gravel and cobble; poor sediment recruitment below the dams; and armoring of smaller gravel and fine sediments (Stillwater Sciences 2004).

To determine current trends in sediment transport processes within the Project Area, KHE sampled gravel bars in Lagunitas Creek between the Green Bridge and north of the Giacomini Ranch’s north levees (KHE 2006a). As described earlier, there are several prominent gravel bars within the Project Area, including one downstream of the Green Bridge, one near the cattle-crossing location midway through the Project Area, and one just south of the north levees. Results show that grain-size distributions for the Green Bridge and north levee bars are very similar and are dominated by fine-grained gravel (KHE 2006a). The cattle crossing gravel bar is composed of coarse-grained gravel (KHE 2006a). Field observations of the creek between the north levee and Tomales Bay also indicate a relatively coarse-grained, firm bed, grading from fine-grained gravel at the north levee to medium- to coarse-grained sand at the deltaic outfall to Tomales Bay (KHE 2006a). The coarse-grained nature of these surficial bed deposits indicates that Lagunitas Creek possesses a relatively high sediment transport capacity through the Project Area (KHE 2006a).

Conclusions made from grain-size distribution are supported by modeling results that indicate creek flows are sufficient to mobilize and transport coarse-grained materials observed within the Project Area (KHE 2006a) despite flattening of the creek gradient or slope. As might be expected based on channel geomorphology, the narrow, confined reach upstream of White House Pool and downstream of the Green Bridge tends to transport fines, as well as coarse sand and fine gravel, although stream energy is not high enough to convey coarse gravel and cobble (KHE 2006a). Downstream of White House Pool at the cattle-crossing “gravel bar,” stream power drops slightly where the creek widens, and there is some loss of transport, but relatively little (KHE 2006a). Transport rates generally increase again downstream of the cattle crossing bar through the north levee (KHE 2006a).

Based on stratigraphy, fine or suspended sediment appear to be deposited within adjacent floodplains when flows are sufficient to crest the levees (KHE 2006a). One of the highest depositional areas in the East Pasture appears to be the southwestern corner opposite White House Pool, where the Giacomins apparently deliberately removed or lowered levees to preferentially direct flooding (KHE 2006a), perhaps because of repeated flooding problems in the past during more frequently occurring flood events (~ 3 to 5 years). The 1942 aerial photograph shot just prior to establishment of the Giacomini Ranch and following an average winter without excessive flood scour or sedimentation clearly shows overbank scour and sediment deposits within the southeast portion of the East Pasture, along Lagunitas Creek, and within the West Pasture, from historic overbank flooding events (KHE 2006a). For overbank flooding events, sediment transport rates are highest just at the point of entry near the south levee of the East Pasture, with flow velocity dropping sharply throughout the remainder of the pasture (KHE 2006a). Modeled flow velocity in the south is high enough to transport coarse sand and fine gravel, which, then, based on modeling results, would be deposited in the southern-most fields, which appears to agree with information from sediment coring and aerial photographs (KHE 2006a). Sediment transport in the northern portion of the East Pasture is hindered by persistent ponding of floodwaters caused by reduced outflow, which is limited by the concrete spillway and culvert capacity. In the West Pasture, flow velocity during highly infrequent overbank flooding events (> 12 years on average) does not appear sufficient to transport sediment through the pasture, with most sediment probably deposited immediately on the floodplain after cresting the levee (KHE 2006a).

While the upstream reach of Lagunitas Creek does have the highest and perhaps most intrusive levee system, from historic maps, it appears that this section of creek was naturally somewhat narrow and confined, at least during recent recorded time. Therefore, the levees may not have changed fluvial sediment transport processes substantially in the reach upstream of White House Pool relative to “natural” conditions. The other potential impediment, Green Bridge, which almost completely spans the active floodplain of the creek, also does not appear to be having a substantial negative impact on transport processes (KHE 2006a), although the presence of the gravel bar directly downstream again may attest to some effect of the bridge on sediment deposition patterns.

Unlike San Francisco Bay, not much is known within Tomales Bay or the Project Area about estuarine sediment transport processes. Within the Project Area, Lagunitas Creek is well-mixed and fresh, usually well below 2 ppt, during the period of highest freshwater flows and contaminant contribution. If the classic Null Zone were to occur during the winter and early spring, it would be at some point in Tomales Bay itself, where channels are deep enough – and tidal currents are strong enough – to create gravitational circulation and strongly stratified conditions despite the high volume of freshwater flow. Based on longitudinal salinity gradients, gravitational circulation does exist upstream of White House Pool, but only very briefly in the late spring and early to mid-summer, when sediment, nutrient, and contaminant loads are much lower. Typically, ETM are generated through a combination of sediments that are resuspended by strong tidal currents and that are being carried in suspension by river and creek flows. Based on hydraulic modeling results, the strength of tidal currents is not sufficient within the portion of Lagunitas Creek in the Project Area to mobilize even fine sediments except for directly downstream of the cattle crossing gravel bar (KHE 2006a), however, the full complexity of stratified estuarine circulation and associated transport processes may not be captured by a one-dimensional model that is vertically or depth-averaged. ETM may also develop within the Project Area based on other physical forces such as flocculation of creek-borne sediment and organic material induced by increased salinity within waters (Arthur and Ball 1979) or bathymetrically controlled changes in creek circulation and sediment transport patterns due to shoaling at the two gravel bars downstream of White House Pool. While estuarine sediment transport processes have not been as well studied in this watershed as fluvial ones, these processes also have strong implications not only for patterns of sediment deposition in the Project Area, but the potential for the Project Area to improve water quality conditions within southern Tomales Bay by trapping suspended sediment that may be bound to nutrients, bacteria, or other contaminants.

Fish Hatchery Creek. Fluvial transport processes were not specifically modeled, but historical information on past flooding events indicates that flow velocities decrease appreciably once the creek gradient begins to flatten at the base of the Inverness Ridge, creating excessive deposition or debris flow even during relatively mild storm events. During storms, substantial amounts of loose, granitic material from the Inverness Ridge mobilizes and moves down to the valley below, with anecdotal reports suggesting that as much as 10- 12 feet of sediment may have deposited along the base of the Inverness Ridge as a result of extensive debris flows. Over longer periods, these repeated mobilizations of sediment manifest as large alluvial fans on which most of the adjacent homes are constructed. Alluvial fans also occur along the West Pasture perimeter where other Inverness Ridge creeks flow into the West Pasture, including the 1906 drainage. Based on the extent of past excavation, the depositional zone probably extends just downstream of where Fish Hatchery Creek makes a 90 degree turn to flow northward towards the north levee. Tidal current velocities are only high enough near the north levee to move sediment under average and extreme conditions, although extreme tides may be capable of moving silt and fine sand downstream of the levee in the undiked portion of Fish Hatchery Creek (KHE 2006a).

Bear Valley Creek and Olema Marsh. Similar to Lagunitas Creek, the history of Bear Valley Creek is one also marked by discontinuities in the sediment transport, this time, due to infrastructure and creek maintenance activities. As described earlier, Bear Valley Creek has been subjected to a variety of disturbances, including damming; road and berm construction within and across its floodplain; culvert installation; natural and anthropogenic fill in the active floodplain and terraces; channel realignment for construction of the Park Service maintenance facility; and dredging to decrease flooding of the Park Service administrative headquarters. All these disturbances have served to disrupt the sediment transport equilibrium within the creek and Olema Marsh. As was noted earlier, during the 1960s-1970s, the middle section of Bear Valley Creek was incised, meaning that the depth from the top of channel bank to the channel bottom was pretty deep, measuring roughly 6 to 8 feet (KHE 2006b). The incision showed that the channel was out of equilibrium, with sediment loss greatly exceeding sediment gain.

After the 1982 flood, Bear Valley Creek underwent some very dramatic changes as a result of catastrophic debris flows from the Inverness Ridge (USGS 1982). Debris flows originating in the two major tributaries of Bear Valley Creek carried into the mainstem of Bear Valley Creek, choking the former channel and turning the colluvial valley bottom into a sandy, braided stream channel with extensive woody debris jams that acted to temporary dam and pond waters within the channel. In essence, the natural event reshaped Bear Valley Creek, converting at least the middle reach from a net erosional to a net depositional system.

Dynamics of this system are complicated, however. While sedimentation did increase after the 1982 flood, it appears, based on sediment borings conducted by KHE, that much of this sediment is not moving from the middle reach of Bear Valley Creek into the lower and Olema Marsh portions (G. Kamman, KHE, pers. comm.). As discussed earlier, sediment borings in these areas point to increases in elevation being from accumulation of peat or undecomposed organic matter, rather than sediment. Sediment within Bear Valley Creek may be trapped upstream in the reach that has been dredged historically (G. Kamman, KHE, pers. comm.). Modeling results suggest that, if sediments were capable of reaching Olema Marsh, that it would be a depositional environment because of the reduction in flow velocities (KHE 2006a). Under extreme flooding, flow velocities might be high enough for transport of silt and fine sands, but these would drop out of suspension mid-way through Olema Marsh (KHE 2006a). In the case of both floods and tides, which are limited in extent in Olema Marsh, conveyance of sediment would appear to be highest at the Levee Road culvert, where funneling of flows through a narrow constriction tends to increase stream power and velocity (KHE 2006a).

Hydrologic Processes and Wetland Functionality

Some of the most important functions played by wetlands relate directly to the presence and condition of hydrologic processes, including components linked to hydraulics, geomorphology, and hydrodynamics of fluvial or stream and tidal systems. These functions include dissipation of flood flow energy, retention of floodwaters, water quality improvement, carbon export, and wildlife habitat use and support. Streams that are able to connect with functioning, vegetated floodplains can buffer humans and wildlife from impacts associated with flooding and poor upstream water quality. In addition, these same areas support wildlife not only by providing habitat and food within streams and floodplains, but by exporting food and organisms downstream to larger water bodies. The ability of systems to provide hydrologic functions such as these decreases when streams are leveed or become too deep (incised) and are not able to connect with their floodplains. In addition, development of floodplains for commercial, residential, and, to some extent, agricultural purposes also reduces wetland functionality.

Lagunitas and Tomasini Creeks are leveed, although topographic surveys suggest that they are not incised or that the bottom elevation of channels has not deepened through erosion. As discussed earlier, depending on the exact reach within the Project Area, Lagunitas Creek still connects within its floodplains in the Giacomini Ranch for flood flows that occur, on average, between 3.5 years to 12 years, with flooding in the upstream portions probably exceeding 50 years (KHE 2006a). However, they are not flooded under the most frequently occurring flows, those with a recurrence interval ≤ 2 years, which often correspond to some of the important flows from a geomorphic perspective in terms of channel creation and maintenance, sediment transport, etc. There are no flooding recurrence estimates for Tomasini Creek, but, according to the Giacominis, Tomasini Creek overtops the levee near the Giacomini Hunt Lodge during some of the larger storm events (KHE 2006a). Fish Hatchery Creek has not been leveed within the Giacomini Ranch West Pasture and is well-connected to its floodplains, although the Giacominis occasionally deepen the channel through sediment removal. Rapid aggradation of Bear Valley Creek since the 1982 flood has resulted in reconnection of lower Bear Valley Creek with its floodplains, including in Olema Marsh. Flooding in relation to adjacent private residences and county roads will be discussed in more detail under Public Health and Safety.

Some of the riparian vegetation along the southern portion of Lagunitas Creek adjacent to the Giacomini Ranch – where vegetation would be expected to naturally occur – has been removed and/or precluded from establishing by placement of riprap, although quite a few stands remain, particularly on the lower portions of the bank. In fact, approximately 75 percent of Lagunitas Creek banks with potential to support riparian habitat are vegetated with riparian species despite past levee maintenance efforts. This vegetation increases the ability of this section of creek to dissipate flood flows. Riparian loss along Tomasini and Fish Hatchery Creeks is much more extensive, with approximately 40 percent and 25 percent of the Tomasini and Fish Hatchery creek banks, respectively, supporting riparian vegetation where it would be expected to naturally occur. Historic riparian loss apparently occurred along Bear Valley Creek when it was actively ranched, but, since ranching ceased, riparian vegetation has rapidly recolonized, although increases in water levels within the lower portion of the creek, including the marsh, appear to be drowning some of the mature riparian trees.

Not only do levees keep waters out, thereby decreasing floodwater retention capability, they also keep any waters that do occur such as from precipitation, run-off, or groundwater inside the levees, thereby decreasing the potential for exporting carbon and other food sources to downstream water bodies. Water quality monitoring indicates that dissolved organic carbon within drainage ditches, ditched sloughs, and creeks is relatively high, but this carbon source is unavailable to organisms in Tomales Bay, because waters are trapped within the pastures by the levees (Parsons, *in prep*.). To a lesser extent, export of carbon produced within Olema Marsh is also minimized by the poor hydraulic connectivity between the marsh and Lagunitas Creek (Parsons*, in prep*.).

Loss of floodplain connectivity for more frequent flood flows such as floods occurring every one to two years not only decreases the ability of the Project Area to store floodwaters, but also to improve the quality of downstream waters. Floodwaters carrying nutrients, sediment, pathogens, and other contaminants from upstream portions of the watershed flow onto floodplains, where plants and even topography act to slow down waters and cause these contaminants to drop out of suspension onto the floodplain. Most of these nutrients and contaminants are chemically bound to suspended or fine sediment in flood flows. Once deposited onto floodplains, nutrients can be uptaken by plants or used by bacteria or retained within sediments for potential release at later periods. Metals and organic contaminants are often effectively “locked” into anaerobic wetlands soils for extended periods of time and only released if wetland conditions drastically change, which is why wetlands are often used for treatment or polishing of wastewater. Changes in stream gradient, stream channel width, or shoals or gravel bars can also encourage deposition of suspended or fine sediment within channels, as well as floodplains. Based on field investigations and hydraulic modeling results, widening of the creek just downstream of White House Pool reduces streamflow velocity – and power – enough to create and maintain the bar composed primarily of coarse gravels at the cattle crossing location, probably during larger flood events. This feature may then influence deposition of slightly finer materials such as coarse sand and fine gravel downstream of the gravel bar during lesser flood events by acting as a shoal.

In addition to overbank flooding or in-channel deposition of suspended sediment during flood events, wetlands and aquatic systems can also trap contaminants through estuarine sediment transport processes such as ETM established by Null Zones or other hydrodynamic or circulation-related forces. The interaction between salt and freshwater in transitional zones such as the Project Area can create zones of high turbidity and potential sediment deposition through development of upward moving water currents or Null Zones or flocculation of sediment and organic material when freshwater encounters saltwater, which has a higher electrostatic charge. These estuarine sediment transport processes combine with fluvial ones to increase the complexity of sediment transport and deposition dynamics within transitional zones. The processes controlling estuarine sediment transport and deposition in Tomales Bay have not been specifically studied, but it is highly probable that ETM occur within the Bay and even the Project Area and that these ETM would have strong implications potentially for water quality improvement and aquatic biota.

Water Resources – Water Salinity and Water Quality

One of the most important functions that wetlands play is the improvement of water quality, which may be that much of the wetland protection regulations relate to water quality. Wetlands improve water quality through trapping of sediments, nutrients, and contaminants, which are either retained or transformed in soils or uptaken by plants. The value of wetlands for water quality improvement has encouraged many municipalities to develop treatment wetlands specifically for at least polishing and refining of treated wastewater.

Water Salinity

Regulatory and Policy Setting

Salinity is typically not a regulated parameter of water “quality,” but within certain regions, salinity can be a concern. Discharge of agricultural waters and run-off can increase concentrations of agricultural “salts” (i.e., conductivity or conductance) within downstream water bodies, which can affect aquatic biota. Conversely, increases in duration and volume of freshwater inflow from releases of treated wastewater can change salinity dynamics within estuaries, converting saltwater wetlands to freshwater ones. Large acreages of wetlands within south San Francisco Bay have shifted from being saltwater wetlands to brackish or even freshwater ones because of large volumes of year-round treated wastewater release. The RWQCB has attempted to stop this trend by requiring many sewage treatment plants to store treated or re-use wastewater during the summer to ensure that salinity dynamics of the estuary do not continue to be altered. In the 1995 Basin Plan, the RWQCB states that, “controllable water quality factors shall not increase the total dissolved solids or salinity of waters of the state so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat.”

Regional and Tomales Bay Setting

Salinities within Tomales Bay are dictated largely by the degree of tidal and freshwater influence, although other factors can affect salinities and salinity structure such as estuarine geomorphology, current, evaporation, bathymetry, wind, and other hydrodynamic processes. As was described earlier, previous studies and recent three-dimensional hydrodynamic modeling of Tomales Bay showed that different circulation patterns occur in the outer, inner, and even middle portions of the Bay, which greatly affect salinity conditions (Largier et al. 1997a, 1997b; Harcourt-Baldwin 2003; Gross and Stacey 2003). Near the mouth, strong tidal currents and a channel-shoal structure consistently maintain ocean water salinities, although salinities may briefly be reduced periods of heavy freshwater inflow (Hollibaugh et al. 1988, Harcourt-Baldwin 2003, Gross and Stacey 2003). In contrast, salinities in the middle and inner bays are highly variable, both temporally and spatially. Throughout the year, waters in the middle and inner portions of Tomales Bay vary from well-mixed and nearly fresh after heavy winter runoff to strongly or partially stratified during spring and early summer and potentially even slightly hypersaline in late summer (Hollibaugh et al. 1988, Harcourt-Baldwin 2003, Gross and Stacey 2003) depending on natural variation in summer flows, as well as mandatory and non-mandatory releases from watershed reservoirs. This seasonal variability is accentuated by spatial variability, with numerous large and small creeks and perhaps even groundwater discharge points leading to multiple saltwater-freshwater interfaces along the Bay's perimeter.

These physical interfaces between freshwater and saltwater result in creation of a very dynamic portion of estuarine systems – the transitional zone between saltwater and freshwater. Based on freshwater inflow, the Project Area represents the largest transitional zone within Tomales Bay. Unlike salt marshes in marine-dominated systems, where salinities remain relatively constant throughout and between years, salinities change dramatically both within and between years in these transitional zones in response to seasonal and annual changes in freshwater flow. These seasonal and annual changes in salinity within transitional zones can exert a tremendous influence on ecosystem dynamics by radically altering the diversity and types of organisms present, as well as influencing localized and downstream water quality conditions through sediment deposition and resuspension. Long term changes in freshwater flow related to decadal trends in climate or anthropogenic disturbances such as increases in freshwater flow diversion or increased freshwater flow during the summer can even alter the composition of vegetation communities. One of the largest transitional zones in the San Francisco Bay region is Suisun Bay in the San Francisco Bay – Sacramento Delta estuary.

Salinities within most transitional estuarine zones vary markedly throughout the season, ranging from freshwater conditions (0.2 to 0.5 ppt) in the winter and spring to saline or euhaline (30-40 ppt) conditions in summer. Salinity conditions are not only determined by the volume and duration of freshwater flow, but by circulation patterns driven by physical forces such as tides, density and temperature gradients, wind, bathymetry, and even evaporation. In "classic" estuaries, longitudinal density gradients related to salinity typically result in stratification of waters, often during the spring and/or summer, with freshwater flows creating a lens of less dense freshwater or brackish water on the water surface and tides driving a wedge of denser, saltier water upstream on the channel bottom. During the rainy season, depending on the volume of freshwater flows, tidal influence can be minimized or even eliminated, resulting in a uniformly fresh water column. In the summer and fall, particularly in systems where freshwater flows cease or decrease substantially, water salinity -- and structure of salinity within the water -- can be determined more by the degree of tidal influence, tidal cycle, vertical mixing induced by winds, tidal currents, or bathmetry, and temperature-related evaporation, leading to either salinity-stratified or well-mixed brackish, saline, or even hypersaline conditions that can vary depending on month, tidal cycle, or water depth (Kimmerer 2004, Schoellhamer 2001).

One of the most well-studied components of transitional zones in San Francisco Bay is the Low-Salinity Zone or X2. The LSZ or X2 refers to a hydrologic zone or geographically variable portion of the estuary with salinities of approximately 2 psu (~2 ppt), which has been used in San Francisco Bay as an index of the physical response of estuary to freshwater flow and the effect of freshwater diversions in the Central Valley (Kimmerer 2004). In San Francisco Bay-Sacramento Delta Estuary, investigations into the LSZ and target organism abundance have found significant relationships, at least some of the time, for estuarine-dependent copepods, mysids (*Neomysis mercedis*), bay shrimp (*Crangon franciscorum*), and several fish including longfin smelt (*Spirinchus thaleichthys*), Pacific herring (*Clupea pallasii*), starry flounder (*Platichthys stellatus*), Sacramento splittail (*Pogonichthys macrolepidotus*), American shad (*Alosa sapidissima*), and striped bass (*Morone saxatilis*; Kimmerer 2004). The timescale over which salinity changes can also have a profound effect on estuarine organisms, with gradual changes or stable conditions more beneficial for many species than abrupt changes or fluctuating salinity (Kimmerer 2004). The relationship between salinity and biota is discussed more under Fish and Wildlife Resources. As discussed under Water Resources – Sediment Transport processes, salinity can also affect transport and depositional patterns of suspended sediments through creation of Estuarine Turbidity Maximum (ETM) or zones of increased suspended sediment concentration and deposition to a number of physical processes or properties, including gravitational or classic estuarine circulation, bathmetry, geomorphology, tidal cycles, and flocculation of river-borne sediments and organic material due to increased electrostatic charge of saltwaters (Arthur and Ball 1979, Schoellhamer 2001, Ganju et al. 2004, Kimmerer 2004) .

Lagunitas Creek. The portion of Lagunitas Creek in the Project Area represents a unique component of estuaries – the dynamic interface zone between saltwater and freshwater influences that results in highly variable season and interannual salinity conditions. The Lagunitas Creek delta is one of the largest estuarine transition zones in Tomales Bay and is analogous to the Suisun-lower Sacramento Delta region of San Francisco Bay. Salinity concentrations and structure within Lagunitas Creek appear to be dependent on bathymetry and strongly driven by the natural seasonality of freshwater inflow, corresponding height and range of tides, and deviations from natural intraannual and interannual patterns in freshwater inflow due to reservoir releases (Parsons, *in prep*.).

In the winter (December – April), very uniform freshwater conditions (< 1 ppt) can persist in upstream areas until June, when strong stratification starts to occur with as much as 16 ppt difference in salinities in surface and bottom waters (NPS, unpub. data). Summer freshwater inflow is maintained at minimum levels during both average (8 cfs) and dry (6 cfs) years due to releases from reservoirs mandated by the SWRCB (95-17), which may affect not only overall water salinity, but salinity structure in the Project Area. In the late fall, surface salinities once reached as high as 14 ppt near the Green Bridge, but salinities are typically much lower (< 5 ppt). Salinities decrease appreciably upstream of the Green Bridge during the summer and fall, with conditions often fresh (<0.5 ppt), except during higher high tides when salinities increase after a short time lag to approximately between 1 and 3 ppt (KHE and NPS, unpub. data). Midway through the Project Area, salinity ranged from 0.1 ppt in the winter to 20 ppt in the summer. At the northern end of the Project Area, fresh to slightly brackish conditions (0.1 ppt) are present typically only during the months with rain, with salinities climbing rapidly to 20 to 30 ppt starting in early summer. Results of the hydrodynamic model agreed reasonably well with actual salinities from monitoring data, although the model is a one-dimensional system that averages salinity conditions across depth (KHE 2006a). Within the Project Area, the section of creek upstream of White House Pool is deep enough to become strongly stratified during at least some portion of the year, due, in part, to the water impounding effect of the gravel bar at the cattle-crossing location (Parsons, *in prep*.). Downstream of this gravel bar, the creek widens and becomes shallower, and salinity structure within this reach is usually only partially stratified or even well-mixed (Parsons, *in prep*.).

Some data from 2003 exemplifies this conclusion (NPS, unpub. data, Parsons, *in prep*.). During the rainy season, salinities were uniformly low (0.1 ppt), both within the water column and Project Area. Starting in May, salinities remained low and uniform (0.1 -0.5) in the Project Area, except for the north levee, where salinities increased to approximately 5 ppt. During the June sampling date, salinities increased above freshwater conditions everywhere except at the Green Bridge, but there was only slight stratification within the White House “Pool” (e.g., 0.9 to 1.3 and 2.5 to 2.8). During July, salinities became highly stratified at least within the “Pool,” with surface salinities at 3.7 and bottom salinities of 21.6 at White House Pool proper, probably because freshwater inflow, as regulated by reservoir releases, was relatively strong. In August and succeeding fall months, the degree of stratification upstream of White House Pool decreased or even disappeared at times and appeared to become more dependent on an interaction between freshwater flows and tidal cycle. From August through December 2003, the LSZ, represented by bottom salinities of 2 ppt, entirely disappeared from this section of Lagunitas Creek.

The influence of bathymetry on salinity concentration and structure is not only apparent from the stratification within the “Pool,” but the fact that, occasionally, higher salinity waters appear to pool between the cattle-crossing location and north levee gravel bars, creating a saltwater “pool” in the midst of the Project Area (Parsons, *in prep*.). In October and November 2003, higher salinity waters ranging around 28 ppt were observed midway through the Project Area, while waters downstream at the north levee ranged from 21 to 24 ppt (NPS, unpub. data). Hydraulic modeling results point to the cattle crossing gravel bar have a significant effect on salinities within the creek: if the gravel bar were not present, maximum salinities within the creek upstream of White House Pool could increase by as much as 35 percent (KHE 2006a).

Salinity and salinity structure is also governed by the pattern of freshwater inflows, particularly during the summer and fall months. In unregulated systems within Mediterranean climate systems, salinities might increase steadily in response to natural hydrologic patterns of steady decreases in freshwater inflow superimposed over small-scale daily variations in evaporation and evapotranspiration. Diurnal variations in flow from evaporation or evapotranspiration associated with vegetation represented as much as 10 percent of the mean stream discharge for the Merced River, with rate dependent on total vegetation cover and ambient temperatures (Lundquist and Cayan 2002). However, in regulated systems such as Lagunitas Creek, salinity structure may also be influenced by daily variation in reservoir releases, as well as pumping or withdrawal rates for NMWD wells and other stream diversions (Parsons, *in prep*.). Randomly selected average daily discharge data from the USGS Point Reyes Station gage shows some interesting small-scale variations in freshwater inflows during the summer of 2001 and 2002 (Figure 29). This gage is far enough upstream that it is not subject to tidal influence, except during extreme events (G. Kamman, KHE, *pers. comm.*). For example in 2001, stream discharge dropped from 12 cfs to 6.75 cfs within approximately 9 days, followed by a sharp, temporary increase from 7.0 cfs to ~9.4 cfs over the period of one to two days (Figure 29). In summer 2002, stream discharge dropped from 13 cfs to 9.5 cfs over 1 to 2 days, followed later by a sharp increase by approximately 2 cfs over another 1 to 2 days (Figure 29). Whether natural or unnatural, fluctuations in freshwater inflow, particularly sharp ones, as shown in Figure 29, would have substantial effects on salinity patterns, both within stratified and mixed portions of the creek (Parsons, *in prep.*). Modeling results for Lagunitas Creek suggest that changes in stream discharge of 2.0 cfs can result in increases in doubling or 100 percent increases in maximum water salinities (KHE 2006a).

Tomasini and Fish Hatchery Creeks. Similarly, as freshwater flow in Fish Hatchery and Tomasini Creeks decreases, salt "wedges" move up the creeks, although the upper portions of at least Tomasini Creek often go dry during the summer and early fall months. Salinity concentrations within Tomasini Creek varied between a maximum of 27-ppt during the summer and 0.1-ppt during the winter (KHE 2006a). The movement of the salt wedge upstream during the summer results in brackish water conditions (~18 – 22 ppt) occurring near the Giacomini Hunt Lodge (KHE 2006a). Perennial fresh water conditions exist at the confluence of Tomasini Creek and Mesa Road. At Fish Hatchery Creek, salinity ranges from perennial fresh waters at the furthest upstream location near Sir Francis Drake Boulevard, progressing toward more saline and seasonally variable waters downstream in the West Pasture (Parsons, *in prep.*). By late summer, freshwater flows have decreased enough to allow the salt wedge to move midway through the West Pasture across from the Lucchesi-Kostelic residence. Salinities of the West Pasture Old Slough tributary are consistently higher than those of Fish Hatchery Creek, probably due to the more seasonal nature of the freshwater inflow. At the West Pasture Old Slough, salinities range from 0.1- to 5 ppt in the winter and 20- to 30 ppt in the summer. During the summer and fall, salinities at the north levee and in the undiked portion of Fish Hatchery Creek are closer to euhaline, ranging from 20 to 30 ppt.

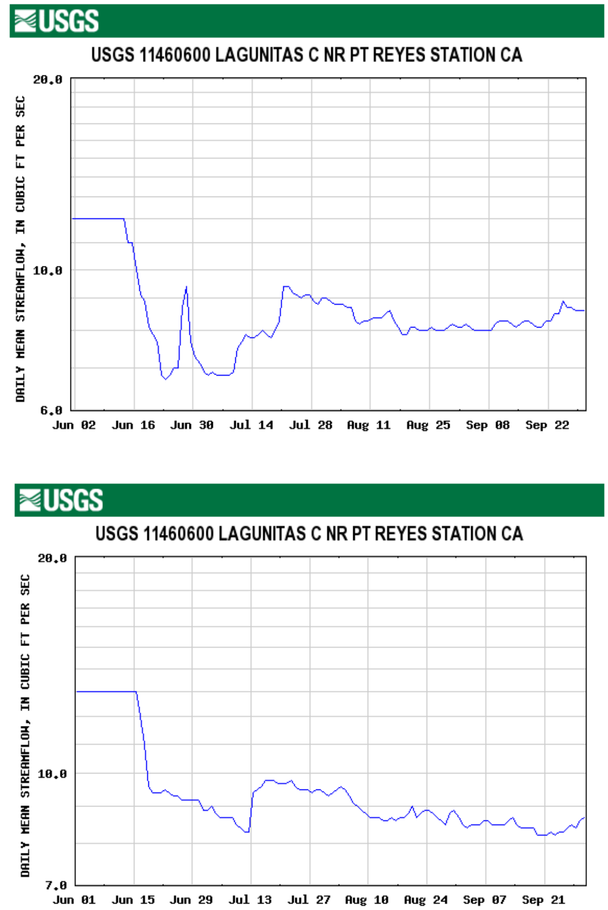

Figure 29. Daily Average Flow, June 1- September 30, 2001 (upper)
Daily Average Flow, June 1 - September 30, 2002 (lower)

Based on data from 2003, salinity patterns and structure are similar to Lagunitas Creek in that stratification only occurs within certain reaches of Tomasini and Fish Hatchery Creeks during specific seasons, with occurrence dependent on the interaction between freshwater inflow and tides (Parsons, *in prep.*). The water column shows uniform or partially stratified salinities throughout the creeks through June. Strong stratification occurs at deeper sections of the creeks – the central portion of Fish Hatchery and the section of Tomasini south of the Giacomini Hunt Lodge – July and/or August due to the persistence of at least moderate freshwater inflows. Stratification within these deeper sections disappears or is reduced during the early fall in response to decreased freshwater inflow and shallower water depths, resulting in more mixed conditions. Stratification is reestablished in deeper sections during some of the early winter storms, (e.g., 0.4 at the surface and 24.1 at the bottom at Fish Hatchery Creek in November 2003), with conditions turning uniformly fresh once rainfall is persistent.

Giacomini Ranch East Pasture. Areas such as the East Pasture that is not directly influenced by tides and creeks show seasonal patterns and stratification in salinities, as well, although the patterns are somewhat reversed (Parsons, *in prep.*). During the summer and fall 2003-2004, salinities within the drainage ditches and East Pasture Old Slough remain relatively low (~0.2 to 0.8) probably due to pumping of irrigation water into the ditch and slough system. However, during the months of January through March, salinities within the ditch and Old Slough actually increase to between 1.5 to as high as 9.4, with stratification of fresh and saltwater occurring in some of the relatively deep sections. Irrigation appears to drive down salts during the summer months. Starting in April or May, salinities decrease again and remain low until the following January. The only exception to this is the very northern end of the East Pasture Old Slough, which, despite being cut off from Lagunitas Creek by a dike and one-way flapgate, shows more typical patterns in salinities, with salinities increasing through the summer and fall and dropping during the winter. Areas such as the shallowly flooded vegetated flat near the Point Reyes Mesa and the New Duck Pond are seasonally flooded, with salinities averaging approximately 4 and 1 ppt, respectively. Only the drainage ditch in the Tomasini Triangle at the base of the north-facing Dairy Facility Mesa slope showed consistently fresh- to very low brackish salinities, with salinities never exceeding 0.6 and averaging 0.2 ppt.

As discussed earlier, the source of salts for surface waters within diked portions of the East Pasture appear to result from persistence of residual marine salts deposited when the areas were not diked (KHE 2006a). In addition, the northeastern portion of the East Pasture is being affected by tidal inflows from Tomasini Creek that are being routed through a culvert in the levee into the drainage ditch and shallowly vegetated flat used by waterfowl and shorebirds (Parsons, *in prep*.). Salinity of groundwater was consistently higher throughout the year than that of surface waters, probably due to the limited infiltration of irrigation waters and direct contact with soil horizons containing high concentrations of residual salts. Groundwater salinities were quite variable in the northern and central portions of the East Pasture, ranging from 6 to 40 ppt during the three years of monitoring (NPS, unpub. data). Salinities in the southern portion of the East Pasture, which represents the highest elevations, ranged from only 2- to 5 ppt, probably due to the minimal influence of tides historically at the base of the alluvial fan and the presence of significant groundwater seep and spring flow from the Mesa (NPS, unpub. data). Groundwater salinities in the Tomasini Triangle in the far eastern portion of the East Pasture surprisingly ranged as high as 5- to 9 ppt (NPS, unpub. data). Based on modeling, topography, and historic maps, this area appears to have once been part of an alluvial fan or plain at the mouth of Tomasini Creek and, at least based on current topography, would be above the influence of almost all tides (KHE 2006a). However, data suggests that extreme tides probably once reached this area.

Giacomini Ranch West Pasture and Freshwater Marsh. The West Pasture is not as heavily ditched as the East Pasture, because it is not irrigated. However, it is more heavily influenced by small drainages and groundwater seeps from the Inverness Ridge. These hydrologic sources have generally created a freshwater to saltwater gradient from west to east, as well as from south to north (Parsons, *in prep*.). Northern portions of the West Pasture appear to be saltier due to overbank flooding of limited tidal action through the north levee modified tidegate and groundwater interaction with residual salts in the soil (See East Pasture discussion above). Salinities in the northern portion of the West Pasture along its western perimeter are consistently low due to the strong seasonal to perennial influence of groundwater.

One exception to this salinity gradient occurs within the West Pasture freshwater marsh. Long-term salinities within this marsh prior to 2003 are unknown, but some spot sampling in a few areas associated with amphibian surveys found salinities during the winter that ranged from 0.1 ppt to 0.8 ppt (Fellers and Guscio 2002). Interestingly, while vegetation composition pointed to the marsh largely being “fresh,” salts were detected in the groundwater (NPS, unpub. data). Salinities in shallow groundwater wells within the marsh ranged from 0.3 to 4.4 during late fall 2002 and early 2003 (NPS, unpub. data). This is suggestive of a historic source of salts within the soils, probably to tidal influence prior to diking. Based on the 1862 U.S. Coast Survey map, the West Pasture freshwater marsh was almost completely subtidal or unvegetated intertidal habitat with just a thin fringe of land apparent on the western perimeter. Salts from tidal influence during this period have probably remained in the peaty clay soils despite diking and a conversion from marine or brackish to predominantly freshwater conditions.

In winter 2003, the West Pasture freshwater marsh experienced much higher salinities due to collapse of the culverts at the north levee, which appeared to increase the range of tides allowed into the West Pasture and the freshwater marsh. Based on changes in the vegetation, it appeared that this change in tidal range was dramatically affecting salinities within the marsh (NPS staff, pers. obs.). Monitoring of salinities within the surface waters in July and August 2003 showed that salinities increased to as high as 6 - 35 ppt within this marsh, although groundwater seepage and flow from drainages appear to maintain a freshwater lens of less than 1 ppt at the western perimeter of the marsh or on the water surface (NPS, unpub. data, KHE, unpub. data). Following repair of the tidegate, tidal amplitude within the West Pasture was compressed, limiting the range of tides to between 3.4 and 5.25 ft NAVD88, the latter of which appeared to be the height at which saltwater incursion into the freshwater marsh occurs (KHE 2006a). Tidal events triggering water levels of 5.25 feet NAVD88 appear to only occur when water levels within undiked areas exceeds 6.25 to 6.5 feet NAVD88 (KHE 2006a), which are at the higher end of high tides and relatively infrequent.

Culvert and tidegate repair appears to have reduced the extent and duration of salinity intrusion events in the marsh. However, salinity intrusion events still occur. Based on some continuous water quality monitoring in 2004, salinities in the marsh appear to be highest between December and March, despite increased freshwater flow from rainfall (Parsons, *in prep*.). This counter-intuitive pattern – salinities would typically be expected to be highest during the summer – appears to be related to annual trends in extreme high tides, which are at their highest during this period (>7 feet MLLW). In mid-January 2004, high tides exceeding 6.2 ft MLLW occurred within Tomales Bay, thereby probably triggering a salinity intrusion event. In March 2004, salinities in the marsh ranged from as high as 4.68 to 8.13 ppt, averaging 4.2 and 7.4 ppt, in the deepest and shallowest portions of the marsh, respectively (NPS, unpub. data). Over the next two months, salinities dropped to an average of 2.53 ppt in April 2004 and 1.6 ppt in May 2004, and subsequent monthly spot sampling in the summer showed that salinities remained at these levels throughout the summer (NPS, unpub. data). This water salinity pattern suggests that saltwater intrusion events occur principally in the winter and that the volume of saltwater is high enough to create saline conditions despite very high freshwater inflows from creeks, drainages, and groundwater (Parsons, *in prep*.). In addition, the extended period over which salinities dropped points to long residence time for saltwaters, probably because the highly vegetated and depressional basin structure of the marsh discourages exchange or draining to nearby Fish Hatchery Creek (Parsons, *in prep*.).

Saltwater intrusion events do not necessarily affect the entire West Pasture freshwater marsh. Within the marsh, tidal flows appear to move up the western perimeter of the marsh near Sir Francis Drake Boulevard and then disperse over the marshplain into lowest, deepest portions of the marsh in its center (Parsons, *in prep*.). Based on long-term salinity monitoring, it appears that saltwater intrusion occurs exclusively in the northern and central portions of the marsh, representing approximately two-thirds or 5.3 acres of the marsh. A rise in topographic gradient associated with the base of the Inverness Ridge to the west and the alluvial fan of the 1906 Drainage to the south appears to minimize salinity intrusion in the southern one-third (1.9 acres) of the marsh, particularly in combination with perennial freshwater flows from the 1906 Drainage. Salinities in the 1906 Drainage never exceed 0.1 ppt (NPS, unpub. data).

Water Quality

Perhaps, one of the most important functions that wetlands can provide in Tomales Bay is water quality improvement. While Tomales Bay is often considered a relatively pristine estuary, it is still vulnerable to anthropogenic impacts. As was described under Soil Resources, the Bay is subject to impacts from agricultural activities, leaking septic systems and landfills, past mercury mining, boating and boat facilities, offshore oil spills, and potentially even atmospheric deposition of contaminants from more heavily urbanized watersheds. During the last few decades, poor water quality has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak. In 1994, Tomales Bay was listed as threatened under the state's Shellfish Protection Act. Mercury mining during the late 1960s-1970s eventually resulted in deposition of mercury-contaminated sediment into Tomales Bay. Because of mercury problems, fish consumption advisories were established in 2000 and reissued in 2004 for Bay species such as jacksmelt (*Atherinopsis californiensis*), California halibut (*Paralichthys californicus*), and leopard shark (*Triakis semifasciata*; California EPA Fish Consumption Advisories web page; Advisory No. 400404).

The failure of Tomales Bay to consistently meet water quality standards for designated beneficial uses such as oyster mariculture, public recreation, and wildlife needs prompted the RWQCB to designate it as impaired under Section 303(d) of the Clean Water Act. These water quality problems have galvanized public and private efforts to improve water quality through both source reduction and restoration. The Park Service is actively working with community and local government groups on a number of projects related to water quality, the largest of which is the Giacomini Wetland Restoration Project. The Park Service's commitment to improving watershed health is evidenced by incorporation of a watershed-based restoration goal that encourages project proponents to search for opportunities to improve conditions within the entire Tomales Bay watershed, not just the Project Area. The Park Service believes that reestablishing the hydrologic connection between the Bay and this historic salt marsh could play a vital role in improving water quality not only within the Project Area, but within Tomales Bay by retaining and/or transforming sediment, nutrients, and pathogens in floodwaters. Two-thirds of the Bay's freshwater inflow – and therefore potential sources of pollutants -- comes from the Lagunitas and Olema Creeks, which flow through the Project Area (Fischer et al. 1996).

As with sediment contaminants, excessive inputs of nutrients can convert wetlands from a sink to a source. The Giacomini Ranch has operated since the 1940s, but another dairy existed within a portion of the Giacomini Ranch area prior to that. Agricultural operations such as dairies, in which cattle are highly concentrated in both pastures and barn facilities, can increase loading of nutrients and potentially pathogens from manure. Because of concerns that restoration could result in at least a temporary increase in nutrient loading into Tomales Bay should the Ranch have very high concentrations of manure in the pastures, the Park Service implemented monthly to quarterly systematic sampling of field parameters, nutrients (nitrate, nitrites, total ammonia, total dissolved phosphates), chlorophyll a/phaeophytin, and pathogen indicators (total and fecal coliform) within the Project Area and selected reference sites in spring 2002. This sampling program would be continued as part of a long-term monitoring program for the proposed project.

Regulatory and Policy Setting

Increasing concern about polluted waters in the 1960s led to a number of federal and state efforts to improve water quality, some of which led to increasing protection for wetlands, which were recognized for their important role in improving water quality.

The most well-known legislation protecting the nation's waters is the Federal Water Pollution Control Act (Clean Water Act) and subsequent amendments of 1977 (33 USC §1251 et seq.). The Clean Water Act provides for the restoration and maintenance of the physical, chemical, and biological integrity of the nation's waters, primarily through three sections – Section 404, Section 401, and Section 303(d). Section 404 (33 U.S.C. 1344) of the Act prohibits the discharge of fill material into navigable waters, tributaries to navigable waters, and special aquatic sites of the United States, including wetlands, except as permitted under separate regulations by the U.S. Army Corps of Engineers (the Corps) and U.S. Environmental Protection Agency. Under Section 401 (33 U.S.C. 1341), states and tribes can review and approve, condition, or deny all Federal permits or licenses that might result in a discharge to state or tribal waters, including wetlands. In California, authority for Section 401 has been delegated to the State Water Resources Control Board (SWRCB), which shares its authority with nine regional boards (see Porter-Cologne Act below).

The Clean Water Act was actually predated by California's Porter-Cologne Water Quality Act of 1969 (California Water Code, Division 7, §13000), the principal California law governing water quality control in California. The Porter-Cologne Act applies broadly to all State waters, including surface waters, wetlands, and ground water; it covers waste discharges to land as well as to surface and groundwater, and applies to both point and non-point sources of pollution. SWRCB is the lead agency for enforcement and provides for establishment of waste discharge requirements for discharge to the state's surface and groundwater resources. SWRCB shares authority for implementation of the Clean Water Act and the Porter-Cologne Act with regional water boards. Each RWQCB governs one of the nine hydrologic regions into which California is divided, adopting regional water quality control plans (basin plans) for their respective regions. Waste discharge requirements for San Francisco Bay are outlined in the *Water Quality Control Plan for the San Francisco Bay Basin* (RWQCB 1995a). Water quality control plans designate beneficial uses of water for specific water bodies, establish narrative or numerical water quality objectives to protect those uses, and provide a program to implement the objectives. For Lagunitas Creek, beneficial uses include contact and non-contact recreation, oyster production, municipal and domestic water supply, agricultural supply, cold freshwater habitat, fish migration, preservation of rare and endangered species, recreation, fish, spawning, and wildlife habitat. For certain water quality objectives such as total and fecal coliform, specific numeric criteria have been developed for different beneficial use types. A list of the most relevant water quality objectives is provided in Table 8. These numeric criteria often specify a maximum or minimum or one-time "not to exceed" concentration or range of values, but also include measures of central tendency such as average or median concentrations (the central or middle value) over specified periods of time.

Should water bodies violate water quality objectives for its beneficial uses, the state is authorized under Section 303(d) of the Clean Water Act to declare these areas as "impaired" or unable to perform designated beneficial uses by specified contaminants. Both Lagunitas Creek and Tomales Bay have been declared impaired under Section 303(d) for excessive sedimentation and high levels of nutrients and pathogens. Tomales Bay has also been listed for mercury. In recent years, the RWQCB has been changing its primary focus from regulating point source discharges only to managing point and non-point source pollutant loads within entire systems or water bodies through setting Total Maximum Daily Load (TMDL) standards. The RWQCB has finalized the Tomales Bay Pathogen Total Maximum Daily Load (TMDL) standard and will be establishing TMDL standards for mercury, sediment, and nutrients over the next five years for Tomales Bay, Lagunitas Creek, and Walker Creek (http://www.waterboards.ca.gov/ sanfranciscobay/tmdlmain.htm). A nutrient TMDL has also been planned, but a schedule for this was not available.

TABLE 8. SELECTED WATER QUALITY OBJECTIVES UNDER THE SAN FRANCISCO BASIN PLAN

BACTERIA[a]	Beneficial Use or Habitat/Location	Fecal Coliform (MPN/100ml)	Total Coliform (MPN/100ml)
	Water Contact Recreation	• Geometric mean<200 • 90th Percentile <400	• Median < 240 No sample > 10,000
Basin Plan	Shellfish Harvesting[b]	• Median < 14 • 90th Percentile <43	• Median < 70 • 90th Percentile <230[c]
	Non-contact Water Recreation[d]	• Mean < 2000 • 90th percentile < 4000	
	Municipal Supply/ Surface[e]	• Geometric mean < 20	• Geometric mean < 100
Tomales Bay Pathogen TMDL *TMDL Load Allocation*	Tomales Bay Lagunitas Creek, Olema Creek, and Walker Creek *Lagunitas Creek at Green Bridge*	• Median < 14 • 90th percentile < 43 • Log mean <200 • 90th Percentile <400 • Log mean < 95	
DISSOLVED OXYGEN	Habitat/Location	Numerical Min. Objective	Numerical Median Objective
	Tidal Waters *Bay* *Delta*	5.0 mg/l Minimum 7.0 mg/L minimum	
	Non-Tidal Waters *Cold* *Warm*	7.0 mg/L minimum 5.0 mg/L minimum	Median D.O. for any three consecutive months not < 80 percent.
PH	Habitat/Location	Acceptable Range	Numerical Change Objectives
	All	6.5-8.5	Controllable water quality factors not cause changes > 0.5 units in ambient pH.
SALINITY	Habitat/Location	Narrative Objective/Numerical Change Objectives	
	All	Controllable water quality factors not increase the total dissolved solids or salinity of waters so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat.	
SEDIMENT	All	• Suspended sediment load and suspended sediment discharge rate not be altered in such a manner to cause nuisance or adversely affect beneficial uses. • Controllable water quality factors not cause a detrimental increase in concentrations of toxic pollutants in sediments or aquatic life.	
TEMPERATURE	Inland Waters – Cold and Warm Habitats	• Natural receiving water temperature not altered unless demonstrated that alteration does not adversely affect uses. • The temperature of any cold or warm freshwater habitat not > 5°F above natural temperature.	
TURBIDITY	All	Waters free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases relatable to waste discharge not > 10 percent in areas where natural turbidity is > 50 NTU.	
UNIONIZED AMMONIA	Habitat/Location	Numerical Objectives	
	All	Annual Median ≤ 0.025	
	Central Bay/Delta	Maximum ≤ 0.16 mg/L	
	Lower Bay	Maximum ≤ 0.4 mg/L	

Notes:
a. Based on a minimum of five consecutive samples equally spaced over a 30-day period.
b. Source: National Shellfish Sanitation Program.
c. Based on a five-tube decimal dilution test or 300 MPN/100 ml when a three-tube decimal dilution test is used.
d. Source: Report of the Committee on Water Quality Criteria, National Technical Advisory Committee, 1968.
e. Source: DOHS recommendation.

Table Source: RWQCB 1995a

The Park Service Management Policies (2006) support federal and state efforts to either preserve or improve water quality. Parks are required to "determine the quality of park surface and ground water resources and avoid, whenever possible, the pollution of park waters by human activities occurring within and outside of parks" (Section 4.6.3; NPS 2006). Furthermore, parks are mandated to "take all necessary actions to maintain or restore the quality of surface waters and groundwaters consistent with the Clean Water Act and all other applicable federal, state, and local laws and regulations" (Section 4.6.3; NPS 2006). Marin County regulates activities that substantially degrade surface or groundwater quality through CEQA review, as well as through grading and stormwater permits. It has established several-water related policies, including reduction of pathogen, sediment, and nutrient (WR-2.2), avoidance of erosion and sedimentation (WR-2.3), and protection of watersheds and aquifer recharge (WR-1.1; CWP 2005). The Point Reyes Station Community Plan (Marin County Community Development Agency 2001) identifies protection of Lagunitas Creek, including its water quality, as an objective.

Nutrients and Other Parameters

Tomales Bay. Tomales Bay has been subjected to intensive study on water quality, bay water mixing and nutrient dynamics through the National Science Foundation, Land Margin Ecosystem Research (LMER) program ((Kimmerer et al. 1993; Chambers et al. 1994; Joye and Hollibaugh 1995; Smith et al. 1996; Largier et al. 1997a; Smith and Hollibaugh 1997; Freifelder et al. 1998, and others). This large data set provides an excellent understanding into the complex nutrient cycling found in shallow, Mediterranean-climate estuaries such as Tomales Bay (TBWC 2003).

Nutrient dynamics within Tomales Bay are driven by both oceanic and terrestrial forces. Tomales Bay is considered a heterotrophic estuary in that ecosystem respiration or conversion of organic matter from non-estuarine sources to inorganic nutrients exceeds external supply or internal production of inorganic nutrients by about 10 percent (Smith and Hollibaugh 1998). While most of these converted organic matter is eventually either lost to the atmosphere or recycled internally, dissolved inorganic phosphorous is exported to the ocean and constitutes the primary "product" produced by the Bay that is directly available to external ecosystems (Smith and Hollibaugh 1997).

Organic matter inputs into Tomales Bay come from terrestrial sources (50 percent) and the ocean (50 percent; Smith and Hollibaugh 1998). As might be expected based on the seasonality of terrestrial and oceanic inputs, research has shown that the external supply of organic matter to Tomales Bay varies over seasonal and inter-annual time scales (Chambers 2000; Lewis et al. 2001). Terrestrial sources consist of organic matter, as well as sediment-bound and suspended forms of inorganic nutrients, from the surrounding watershed that flow into the Bay, typically during high rainfall periods. Most of this organic matter and inorganic nutrients enter the Bay through surface flows of its largest tributaries: as described earlier, Lagunitas Creek and its tributaries account for approximately two-thirds of the surface water freshwater inflow to the Bay, while Walker Creek and other small drainages account for the remaining one-third (Fischer et al. 1996). However, during the summer, groundwater discharge into the Bay contributes about as much nutrient load as does streamflow, while, during the winter, it contributes about 20 percent of that of the much higher winter streamflows (Oberdorfer et al. 1990).

Some of the organic matter and inorganic nutrients in surface waters -- and perhaps even groundwater depending on the discharge point -- flow through fringing and deltaic marshes on the perimeter of Tomales Bay before entering Bay waters. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that, in some marshes with well-developed channels, short water residence times resulting from channelization of short-duration, high-intensity flows may decouple these systems from the nutrient pathway during the winter, reducing their effectiveness in filtering contaminants (Chambers et al. 1994). However, these same systems act as sources of inorganic nitrogen and phosphorous to the Bay during the summer, probably due to breakdown of organic matter (Chambers et al. 1994).

Oceanic sources come from upwelling or funneling of ocean-derived organic matter in offshore currents. The most intensive upwelling occurs during the summer, in response to strong, often persistent northwesterly winds (Smith and Hollibaugh 1998). Upwelling elevates the concentration of particulate organic matter in the coastal waters, which is then delivered to the bay by tides and particle settling (Smith and Hollibaugh 1998). Direct inorganic nutrient delivery from coastal upwelling in the Pacific Ocean is not of major importance to Tomales Bay, but may be important indirectly by affecting nutrient dynamics or cycling within the bay (Smith and Hollibaugh 1998).

As discussed earlier, tides, temperature, salinity, and freshwater inflow rates affect nutrient circulation patterns in Tomales Bay. During the winter, spring, and early summer, the substantial volume of freshwater inflows to the Bay results in a considerable exchange of organic matter and nutrients between the inner and middle portions of the Bay and the outer Bay and ocean. However, as freshwater flows decrease, circulation mechanisms shift from salinity-driven to temperature-driven gradients, which results in weaker exchange of waters between at least the middle and portions of the inner Bay and the outer Bay and ocean (Harcourt-Baldwin 2003). This increases water residence time and persistence of nutrients within the Bay from several days during the winter to more than a month in the summer (Smith and Hollibaugh 1998). As noted earlier, water in the northern 3.73 miles of the bay exchanges with nearshore coastal water on each tidal cycle, while water in the southern 8.7 miles of the bay is resident for approximately 120 days during times of low runoff (Hollibaugh et al. 1988).

In the innermost portions of the Bay, absence of a salinity or temperature gradient with the middle and outer portions can effectively eliminate exchange of waters between these regions (Hearn and Largier 1997, Largier et al. 1997a). This phenomenon, which is accompanied by hypersaline conditions, apparently causes a buildup in dissolved inorganic phosphorous, as well as severe depletion of dissolved inorganic nitrogen (Largier et al. 1997a). Understandably, hypersaline systems "are very susceptible to pollution as even small loadings during the hypersaline phase may be recycled and accumulate, rather than being flushed from the system" (Largier et al. 1997a).

Internal sources of energy or organic matter to Tomales Bay also exist in the form of algae. Algae represent important components of the estuarine food web, as well as sensitive indicators of ecosystem health. Dramatic increases in dissolved or sediment-bound nutrients, combined with warm temperatures and stagnant water conditions, stimulates algal growth, sometimes excessive densities of algae called algal blooms. Besides being sometimes unsightly, algal blooms play havoc with ecosystems by causing massive swings in dissolved oxygen content of waters through over-production of oxygen during the day and depletion at night through uptake or even algae die-off. This oxygen depletion can result in a "fish kill" event in which fish and other aquatic organisms die to the lack or sudden decrease in oxygen. Die-offs of algae can also boost nutrient concentrations through recycling of organic matter. In addition, excreted material from large concentrations of consumers such as bivalves, waterfowl, shorebirds, and even mammals such as seals can noticeably affect localized nutrient concentrations, primarily through increases in ammonia (Judah 2000).

Despite water quality problems, Tomales Bay has not been characterized as an eutrophic estuary (Cole 1989; Chambers 2000; Lewis et al. 2001). Studies in 1985-1986 in Tomales Bay indicated that spatial and temporal variations in primary productivity were similar to variations in phytoplankton biomass (Cole 1989). During summer months productivity was highest in the seaward and central regions of the bay and lowest in the shallow landward region (Cole 1989). This lack of sustained high phytoplankton concentrations suggests that the shallowness of the southern region, its shallow photic depths, wind-induced turbidity, and feeding of benthic organisms keeps the populations at a lower level than other parts of the bay (Cole 1989). However, little is known about the phytoplankton dynamics in Tomales Bay and the shifting location of the maximum chlorophyll-a concentrations – variable used to measure phytoplankton – during different sampling periods indicates the dominant processes controlling phytoplankton biomass vary (Cole 1989).

In general, little is known about the nutrient status of Tomales Bay or the primary sources of nutrients to the Bay. A review of the current literature indicates that the nutrient levels in the watershed could be elevated, but the database is not very extensive (TBWC 2002). With so little seasonal data on nutrient loading from the watershed and nutrient levels in Tomales Bay, trends cannot be determined (TBWC 2002). In addition, most of the 12 water quality studies conducted in the watershed and bay have emphasized total and fecal coliform measurements and not nutrient levels (TBWC 2002). The data that is available has suggested that nutrients are a problem for the Bay and subwatersheds, which is why these areas have been listed by the RWQCB as impaired for nutrients. The RWQCB will be preparing a TMDL for nutrients, but it is not scheduled for the near future (http://www.waterboards.ca.gov/sanfranciscobay/tmdlmain.htm).

There are a few long-term or more intensive synoptic programs. CDFG conducted a 10-year sampling program between 1991-2001(Rugg 2000; Rugg 2002). Results from the last two years of this study showed that standards were exceeded for only three measurements (DO levels and un-ionized ammonia) out of 329 in 1998-1999 and only two measurements (DO levels) in 1999-2000 (Rugg 2000, Rugg 2002). Studies conducted in the upstream portions of the Lagunitas Creek by the Park Service found that nutrients, nitrites, and unionized ammonia did not appear to be problematic, at least in the upper portions of the watershed (Ketcham 2001). Nearly all of the samples collected from the larger stream systems and most of the tributary samples were below detection limits (Ketcham 2001). Interestingly, at least one comparison between historical and current conditions suggested that, after more than a century of discontinuities in sedimentation and material export, export of sediment-bound forms of nitrogen and phosphorous from the upper portions of the watershed appears to have reached steady-state conditions (Smith et al. 1996).

As with pathogens, the primary sources of nutrients to the Bay include agricultural operations (e.g. dairies and beef cattle), leaking or poorly constructed septic systems, domesticated animals such as horses, and non-point source run-off from communities. Because of the preeminence within this rural watershed and concentrated number of cattle, dairies have received the most scrutiny. The Chambers et al. (1994) paper correlated “dairy runoff from pasture lands” in the watershed of one of the two study marshes with consistently high dissolved ammonium and phosphate in downstream marsh waters. However, two recent studies that nutrient loading from animal agriculture may not be as high as previously indicated, particularly loading from pastures (Regional Water Quality Control Board (RWQCB) 1995b); Lewis et al. 2001 *in* TBWC 2002).

In addition, even in situations where dairies are contributing nutrients to the system, an overall decrease in agricultural activities within the Tomales Bay watershed may be the reason that export of nitrogen and phosphorous to the Bay has decreased and reached steady-state conditions (Smith et al. 1996). Not only do dairies generate nutrients, but cattle can cause increases in land erosion. Erosion not only impacts downstream water quality through increases in turbidity and associated decreases in water clarity, but many nutrients, contaminants, and pathogens are principally transported in water as bound or sorbed to sediment particles. Estimates of sediment-bound nutrients vary widely, but, in general, phosphorous appears to be transported bound to sediment more than nitrogen, although nitrogen estimates still ranged as high as 51-57 percent in some systems (Meybeck 1984, Haith and Shoemaker 1987; Walling et al. 1997). Most inorganic nitrogen is transported as soluble nitrate, however, where erosion rates and sediment yields are high, the sediment-associated component of the total nitrogen and phosphorous loads will predominate (Walling et al. 1997). For these nutrients, sediment transport processes, primarily suspended sediment processes, largely govern which areas become “sinks.” As with nutrients, specific information on turbidity, sediment transport processes, and transport of particulate and dissolved forms of nutrients within Tomales Bay is scarce, as most of the past studies have focused largely on changes to the bay’s bathymetry or creek geomorphological processes due to increases – or decreases – in sediment supply.

Giacomini Ranch. Water quality within the Giacomini Ranch has been monitored for four years as part of the planning process. In general, between 2001 and spring 2006, waters within the Giacomini Ranch did not appear to be eutrophic (Parsons and Allen 2004a). With a few exceptions, parameters such as dissolved oxygen, pH, and nitrates only occasionally exceeded water quality objectives in the RWQCB *San Francisco Basin Water Quality Control Plan* or Basin Plan (RWQCB 1995a), which incorporates Tomales Bay as well as San Francisco Bay (Table 8). There were low to moderate concentrations of nutrients and chlorophyll a, even in drainage ditches (ranging from 0.2-1.5 mg/L), with the exception of seasonal pulses (Parsons, *in prep*.). Also, dissolved oxygen and chlorophyll a levels were not characteristic of either highly eutrophic or hypoxic systems, with the exception of some of the drainage ditches and sloughs in the eastern portion of the Project Area (Parsons, *in prep*.).

The RWQCB Basin Plan (1995a) stipulates that, in tidal waters, dissolved oxygen must have a minimum concentration of 5.0 mg/L (approximately 50 percent dissolved oxygen at 15.0 degrees Celsius), and the oxygen concentration for three consecutive months shall not be less than 80 percent of the saturated dissolved oxygen concentration. For non-tidal waters, the dissolved oxygen concentration minimum is 7.0 mg/L for cold water habitat and 5.0 mg/l for warm water habitat. Within some of the ditches and channels in the East Pasture, dissolved oxygen concentrations consistently fell below 5 mg/L within both surface and bottom waters of some ditches and ditched sloughs and were typically even below 2 mg/L (Table 9; Parsons, *in prep*.). The RWQCB objective of 5.0 mg/L was exceeded during 57 percent of the sampling periods in the East Pasture, with oxygen levels below hypoxia (< 2.0 mg/L) and anoxia (<0.5 mg/L) 32 percent and 14 percent of the sampling periods, respectively (Parsons, *in prep*.). The observed hypoxia-anoxia may have been caused by increased oxygen demand from bacteria breaking down organic matter or detritus from vegetation that was disturbed by ditch maintenance (Parsons, *in prep*.). Low dissolved oxygen concentrations also occurred in some of the non-ditched features in the East Pasture, including the East Pasture’s New Duck Pond, where a majority of values below 5 mg/L: the New Duck Pond is a shallowly ponded, artificially created feature that was maintained until recently through seasonal flooding of pumped irrigation waters (Parsons, *in prep*.).

Some of the monitoring locations in Olema Marsh and on Tomasini Creek, Fish Hatchery Creek, and smaller drainages in the West Pasture occasionally had concentrations of dissolved oxygen below 5 mg/L (Table 9; Parsons, *in prep*.). RWQCB objectives were exceeded between 21 and 25 percent of the sampling periods in the West Pasture, Tomasini Creek, and Olema Marsh.

Most of these events occurred in the spring or summer, when oxygen concentrations might be affected by a combination of nutrient loading, increased temperature, decreased flow conditions, and, consequently, an increase in primary productivity that could create rapid diel variation in oxygen levels (Parsons, *in prep*.). Some of the lowest dissolved oxygen concentrations for Lagunitas Creek within the Project Area occurred in April 2003, with most having levels just above 5 mg/L ; Parsons, *in prep*.). These comparatively low concentrations may be tied to upstream reservoir releases of poor quality water or nutrient loading from cattle in portions of the creek upstream of the Project Area (KHE 2006a).

TABLE 9. LIST OF FREQUENCY OF EXCEEDANCE OF RWQCB BASIN WATER QUALITY OBJECTIVES DURING SAMPLING PERIODS

Criteria that are not listed can be found in Table 8. Percentage refers to percentage of sampling events in which objective was exceeded by a single sample: it should be noted that some standards are linked to means or medians of a group of samples collected over specific time periods. Areas are WP (Giacomini Ranch West Pasture), EP (Giacomini Ranch East Pasture), OM (Olema Marsh), TOM (Tomasini Creek), and LAG (portion of Lagunitas Creek in Project Area).

	Consistently Exceed (≥75%)	Regularly Exceed (≥50%)	Occasionally Exceed (≥25%)	Infrequently Exceed (>0%)	Never Exceed (0%)
Dissolved Oxygen (>5.0 mg/L)		EP	OM	WP, TOM, LAG	
pH (>6.5 and <8.5)				EP, WP, TOM, OM, LAG	
Nitrates					
USEPA (10 mg/L)				EP, TOM	WP, OM, LAG
AWWA (1 mg/L)		LAG, OM	EP, WP, TOM		
Nitrites					
USEPA (1mg/L)				EP	WP, OM, TOM, LAG
Unionized Ammonia (≤ 0.16 mg/L)				EP, LAG	WP, OM, TOM
Fecal Coliform (Based on Individual Sample Event Values; Means for Monitoring Period are shown in Bold Italic)					
Shellfish Harvesting (<43 mpn/100ml)	All/ ***All***				
Municipal Water Supply (<20 mpn/100ml)	All/ ***All***				
Water Contact Recreation (<200 mpn/100ml)	EP, OM, LAG/ ***All***	WP, TOM			
Non-Contact Water Recreation (<2,000 mpn/100ml)	***All***	EP		WP, LAG, TOM, OM	
TMDL-Lagunitas Creek (<200 mpn/100ml)	EP, OM, LAG/ ***All***	WP, TOM			
TMDL Load Allocation-Lagunitas at Green Bridge (<96 mpn/100ml)	All/ ***All***				

Source: Parsons, *in prep*.

With some exceptions, surface waters within the Giacomini Ranch generally appeared to meet RWQCB Basin Plan (1995a) objectives for pH in surface waters (Table 9; Parsons, *in prep*.). According to the Basin Plan, pH should fall within the range of 6.5 and 8.5. USEPA standards for freshwater stipulate that pH should be within the 6.5 and 9.0. The West Pasture had the highest number of exceedances for pH, with pH exceeding standards during approximately 9 percent of the sampling periods: most of these exceedances came from pH being below 6.5 (Table 9). Several factors control pH within waters of transitional zones, including tidal influence, the chemistry of surface waters and groundwater, seasonal variation in primary productivity, and biogeochemical reactions within underlying soils. In general, waters in the Project Area appear to be largely circumneutral (~7; Parsons *in prep*.). Baseline pH appeared higher in areas that are either tidal or tidally influenced, as tidal waters tend to be more alkaline (~ 7.8), and in upstream portions of creeks that flow off the Inverness Ridge (Fish Hatchery Creek, 1906 Drainage; ~7.8 – 8.1), which may be related to the underlying chemistry that exists from weathering of this granite-dominated geologic formation (Parsons, *in prep*.).

Conversely, baseline pH might be slightly depressed (~5.9 – 6.6) in locations primarily influenced by groundwater (Parsons and Allen 2004a). Water pHs with more basic or alkaline values (>8.5) typically occurred during the spring and summer when primary productivity of algae is highest due to nutrient loading, warm temperatures, and decreased flow conditions (Parsons, *in prep*.). Water pHs with more acidic values (~5.9 - 6.4) were found in drainage ditches and shallow seasonally flooded areas due probably to breakdown of organic matter and production of humic acids or other biogeochemical acid-producing processes (Parsons, *in prep*.). At least one of these shallowly flooded areas in the West Pasture may have largely accounted for the comparatively high number of exceedances of Basin Plan objectives (Parsons, in prep.). Interestingly, while surface waters within Lagunitas Creek within the Project Area had only one exceedance of Basin Plan objectives, some limited sampling on portions of Lagunitas Creek between the Green Bridge and Nicasio Creek revealed that pH levels in deeper portions of some of the pools were considerably reduced, with pHs ranging from 3.9 to 5.2 (KHE, unpub. data).

Nitrates appear to be the most abundant nutrient in the Project Area (Parsons, *in prep*.). Nitrate concentrations between 2001 and spring 2006 were generally low to moderate (between 0.2 and 3 mg/L) and similar in both the Project Area and undiked reference marshes that were sampled (Parsons and Allen 2004a, Parsons, *in prep*.). Nitrates typically occur when ammonia is converted to nitrates under well-oxygenated conditions and have been linked sometimes to the influence of leaking septic on groundwater. Average nitrate concentrations calculated using statistical procedures to estimate values that were below the laboratory detection limits ranged from as high as 9.2 mg/L in East Pasture to as low as 1.03 mg/L in the portion of Lagunitas Creek in the Project Area, with average values for Olema Marsh, Tomasini Creek, and the West Pasture being 1.65 mg/L, 1.46 mg/L, and 1.27 mg/L (Parsons, *in prep*.). Average nitrate concentrations in undiked reference wetlands had a tighter range between 0.93 mg/L and 1.04 mg/L. Mean nitrate concentrations in the East Pasture would appear close to the USEPA human consumption limit of 10 mg/L, but average concentrations in the East Pasture were highly skewed by a few very high values that exceed USEPA objectives, as evident from the much lower median value, 1.89 mg/L (Table 9; Parsons, *in prep*.). While USEPA objectives (established for human consumption) were only exceeded a few times, the higher average concentrations suggest that the Project Area occasionally to regularly exceeds standards recommended for preventing eutrophication in estuaries and maintaining moderate aquatic diversity (1.0 mg/L; (American Water Works Association (AWWA) 1990); Table 9). Winter concentrations were highest, with pulses often observed during October and January rainfall events (Parsons and Allen 2004a). Within the East Pasture, the consistently highest concentrations of nitrate were detected in the drainage ditches and a ditch that receives seep and spring groundwater flow, as well as stormwater run-off from the town of Point Reyes Station and Giacomini Ranch feed lots (Parsons and Allen 2004a). Based on monitoring data, nitrate concentrations in the East Pasture are higher than many other dairies the Seashore (range of means = ~1.8 - 5.27; Ketcham 2001), although this data is limited, and means were calculated using different procedures to estimate values below laboratory detection range.

As might be expected, despite high concentrations in several sampling locations in the Project Area, the highest instantaneous loading rates for nitrates – or total volume of nitrates discharged at a single point in time based on stream discharge and capacity -- came from Lagunitas Creek, with instantaneous loading rates during an April 2006 storm as high as approximately 220 mg per second (mg/s; Parsons, *in prep*.). However, instantaneous loading rates for Lagunitas Creek were typically below 1.0 mg/s. Conversely, the highest instantaneous loading rates recorded during four years of discrete sampling for some of the other creeks, drainages, and seeps totaled only 0.27 mg/s for 1906 Drainage, 0.96 mg/s for Fish Hatchery Creek, 1.29 mg/s for Bear Valley Creek, and 2.22 mg/s for Tomasini Creek (Parsons, *in prep*.). Some of the East Pasture areas still had comparatively nitrate loads, as well as concentrations, with the highest values ranging from 11.1- to 46.47 mg/s for ditches, including one receiving non-point source run-off from the town of Point Reyes Station (Parsons, *in prep*.). However, technically, these areas do not discharge to downstream water bodies because of the levees and tidegates, so there is no active loading, except perhaps during those infrequent periods when the Giacominis have discharged ditch water to Tomales Bay or when floodwaters overflow the levees.

When oxygen in waters is low, an intermediary form of nitrogen, nitrites, can occur that can cause asphyxia in humans and wildlife by binding to hemoglobin and reducing oxygen transport. Nitrites were almost always below the detection limit (Table 9), although they were infrequently detected (4 exceedances) in the East Pasture, with at least one exceedance of USEPA objectives of 1.0 mg/L for human consumption (Parsons, *in prep*.). Based on RWQCB standards, there were four exceedances of nitrite levels considered toxic to aquatic organisms (>0.5 mg/L), with three of these in the East Pasture ditches and one in an undiked marsh (Parsons, *in prep*.).

Overall, ammonia concentrations between 2002 and spring 2006 were generally either non-detect or very low (<1 mg/L) and similar between the Project Area and undiked reference marshes (Parsons and Allen 2004a, Parsons, *in prep*.). The presence of higher concentrations of ammonia, which is often bound to sediment when transported, typically can be traced to the recent or nearby presence of wildlife or livestock or use of ammonia fertilizers, as ammonia is quickly converted to nitrates under well-oxygenated conditions. The well-oxygenated conditions within most of the Project Area appear to be quickly converting ammonia to nitrates, with ammonia concentrations highest in those sampling locations where oxygen levels are consistently low (Parsons, *in prep*.). These locations included the Giacomini Ranch's East Pasture drainage ditches, the drainage ditch receiving groundwater and feedlot-influenced stormwater run-off from Point Reyes Station, and in Lagunitas Creek following a potential discharge of flood waters from the pasture (Parsons and Allen 2004a). Even in these areas, high concentrations typically represented seasonal pulses (Parsons and Allen 2004a). As with nitrates, these seasonal pulses skewed average concentrations to the high end. For example, average ammonia concentrations calculated using statistical procedures to estimate values that were below the laboratory detection limits ranged from 3.1 mg/L in the Giacomini Ranch East Pasture to 0.25 mg/L in the portion of Lagunitas Creek in the Project Area, while median values for those same areas ranged between 0.41 mg/L for the East Pasture and 0.01 mg/L for Lagunitas Creek (Parsons, *in prep*.). Mean and median estimated ammonia concentrations for some of the undiked reference wetlands were as low as 0.1 mg/L and 0.05 mg/L, respectively (Parsons, *in prep*.).

There are no Basin Plan standards for ammonia (RWQCB 1995a), but the RWQCB has established objectives for unionized ammonia. In waters with elevated pH, temperature, and/or salinity, ionized ammonia converts to unionized ammonia, which is toxic to aquatic organisms. Only two sampling locations exceeded the maximum general limit for most estuarine waters of 0.16 mg/L (Table 9; RWQCB 1995a; Parsons, *in prep*.). These maximum exceedances occurred in a Giacomini Ranch East Pasture drainage ditch and in a Lagunitas Creek sample in April 2003 that may have received stormwater flow from the pastures.

As with ammonia, total dissolved phosphate concentrations between 2002 and spring 2006 generally fell below or slightly above the detection limit (<0.0.05–0.20 mg/L), with the exception of the Giacomini Ranch's East Pasture drainage ditches (Parsons, *in prep*.). The presence of phosphates in the surface waters may be directly attributed to human and agricultural activity impacting runoff into water courses within the Giacomini Ranch (KHE 2006a). The Basin Plan objectives focus on the linkage between high concentrations of phosphates and growth and sometimes overgrowth of algae. No specific concentration-based objectives are presented in the Basin Plan (RWQCB 1995a), however, the recommended concentration of phosphorous to prevent algal blooms within estuaries is 0.01 to 0.1 mg/L (NOAA/EPA 1988), which is generally below the detection limit for phosphates in the Seashore's monitoring program.

Measurable concentrations of phosphates were primarily detected in the Giacomini Ranch's East Pasture drainage ditches and ranged from 0.24–6.8 mg/l (KHE 2006a). Concentrations at other locations such as Lagunitas, Fish Hatchery, and Tomasini Creeks were at or below detection limit (0.10 – 0.20 mg/L) for a majority of the monitoring events (KHE 2006a). Mean phosphate concentrations calculated using statistical procedures to estimate values that were below the laboratory detection limits ranged from 2.76 mg/L in the Giacomini Ranch East Pasture to 0.13 mg/L in the portion of Lagunitas Creek in the Project Area, with other mean values estimated as 0.25 mg/L for Olema Marsh and 0.14 mg/L for the Giacomini Ranch West Pasture and Tomasini Creek (Parsons, *in prep*.). Again, mean values were skewed pulses of phosphates, particularly in the East Pasture, which had median concentrations of 1.34 mg/L, with differences between mean and median less dramatic in other portions of the Project Area (median values ~0.08 to 0.24 mg/L; Parsons, *in prep*.). The hypoxia to even anoxia that exists in East Pasture ditches would encourage flux of phosphates from sediments in the ditch. Mean and median estimated phosphate concentrations for undiked reference wetlands range between 0.11 to 0.32 mg/L for average concentrations and 0.08 to 0.133 mg/L for median concentrations (Parsons, *in prep*.). As with nitrates, the highest loading rates for total dissolved phosphates in the Project Area – or the highest volumes of phosphates relative to stream discharge – comes from Lagunitas Creek, with loading reaching as high as 4.2 mg/s in Lagunitas Creek and maximum values for other creek and drainages being no higher than 0.2 mg/s (Parsons, *in prep*.). Loading rates for the East Pasture, which technically does not discharge to downstream water bodies, would have been no higher than 0.85 mg/s (Parsons, *in prep*.).

There are no numerical Basin Plan (RWQCB 1995a) objectives for ambient turbidity conditions. To some degree, measurements of turbidity generally showed a seasonal trend, with the highest values surprisingly in spring, summer, or early fall: turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks (Parsons, *in prep*.). The production of suspended particles may be due to events such as upstream dam releases, biological activity, cattle activity, earth-moving and other activities within streams, ditches, and other water bodies (KHE 2006a). Turbidity values in Lagunitas Creek were generally below 50 Nephelometric Turbidity Units (NTU), with the exception of the highest measured turbidity of 266 NTU at the Giacomini Ranch north levee in June 2003 (Parsons, *in prep*.). This measurement may be an anomaly or the result of exchange with downstream Tomales Bay waters during an incoming tide or discharge of pasture waters from an adjacent pump, as values upstream in Lagunitas Creek never exceeded an NTU of 26 on this same date (Parsons, *in prep*.). In Tomasini Creek, turbidity generally ranged between 1 and 40 NTU, with spikes occasionally above 50 NTU occurring during the fall (KHE 2006a). Turbidity values for Fish Hatchery Creek generally fell below 50 NTU, with seasonal spikes over 50 NTU observed during the summer of 2003 and 2004 at downstream locations in the West Pasture (KHE 2006a).

Water temperature is controlled by standards established in a separate document that focuses primarily on elevated temperature water discharges such as cooling waters from power plants, but the Basin Plan does specify that the natural receiving water temperature of inland surface waters shall not be altered unless it can be demonstrated that such alteration in temperature does not adversely affect beneficial uses (RWQCB 1995a). Water temperatures varies seasonally within the Project Area, with warmer predominant during the spring, summer, and early fall, when solar radiation increases and water levels decrease (Parsons, *in prep*.). While all organisms are sensitive to high temperatures, temperature has been identified as limiting factors for certain species, including salmonids. Salmonids use downstream transitional zones of tidal creeks for resting habitat during upstream migration in the winter and for refugia and foraging during outmigration during the spring and summer. During two years of monthly monitoring, temperature in streams known to have supported or that are currently used by salmonids, at least on an intermittent or seasonal basis, ranged from an average of 54.2 degrees Fahrenheit (upper portion of Fish Hatchery Creek in Project Area near Sir Francis Drake Boulevard) to 60.3 degrees Fahrenheit (upper portion of Lagunitas Creek in Project Area between White House Pool and Green Bridge; Parsons, *in prep*.).

Continuous temperature monitoring in upstream portions of Lagunitas Creek during the spring and early summer when salmonid outmigration numbers typically peak showed a steady increase in water temperatures from an average of approximately 56.3 degrees Fahrenheit and range of 48.2 to 64.4 degrees Fahrenheit in April 2003 to an average of approximately 65.3 degrees Fahrenheit and range of 59 to 71.6 degrees Fahrenheit in June 2003 (Parsons, *in prep*.). Water temperatures between monitoring locations both in open water and underneath overhanging riparian trees were almost identical despite the fact that riparian vegetation usually helps to keep water temperature lower due to the effects of shading on solar radiation (Parsons, *in prep*.). During a 24-hour period, temperatures typically varied by as much as approximately 6.3 to 10.5 degrees Fahrenheit (Parsons, *in prep*.). One monitoring location consistently had the both the lowest temperatures and the widest daily variation in temperature: the lowest temperatures were consistently 1.8 to 5.4 degrees Fahrenheit lower than other monitoring locations, although the daily highs were often similar (Parsons, *in prep*.). This monitoring location occurs just downstream of the confluence of Bear Valley Creek and Lagunitas Creek on the south bank underneath overhanging riparian vegetation and may be affected by nighttime cooling of waters within Olema Marsh that subsequently flow into Lagunitas Creek (Parsons, *in prep*.).

Olema Marsh. Water quality monitoring in Olema Marsh was not initiated by the Park Service until August 2004, so the amount of data available from which to draw a conclusion regarding resource conditions in Olema Marsh is more limited. While Bear Valley Creek occurs in a relatively pristine watershed, water quality conditions were only slightly better than Giacomini Ranch (Table 9; Parsons, *in prep*.). Dissolved oxygen concentrations generally averaged around 7.7 mg/L, except for August 2005, when levels dropped as low as 2.6 to 4.17 mg/L (Parsons, *in prep*.). The hypoxic conditions were recorded just upstream of Olema Marsh in lower Bear Valley Creek during the morning, which suggests that supersaturation during the midday and afternoon of the previous day may be resulting in anoxia or oxygen depletion during the night in this sluggish, marshy portion of the creek (Parsons, *in prep*.). Despite this, water pH remained consistently circumneutral during all monitoring events, averaging 7.0 (Parsons, *in prep*). Turbidity levels never exceeded 50 NTU, ranging from 5.13 to 28.8 NTU (Parsons, *in prep*.). Water temperatures in Olema Marsh ranged from as low as 50 degrees Fahrenheit in the winter to as high as 59 to 70 degrees Fahrenheit in the summer, averaging approximately 56.5 degrees Fahrenheit (Parsons, *in prep*.).

Nitrates never exceeded USEPA water quality objectives of 10 mg/L for human consumption, but regularly exceeded levels recommended for preventing eutrophication in estuaries and maintaining moderate aquatic organism diversity (1.0 mg/L), ranging from 0.96 to 2.9 mg/L between August 2004 and April 2006 and averaging 1.65 mg/L (Table 9; Parsons, *in prep*.). Concentrations flowing into Olema Marsh almost always exceeded those flowing out of the marsh, which suggests an upstream source for this nutrient (Parsons, *in prep*.). Nitrate loading rates at the upstream sampling location ranged from as low as 0.01 to as high as 55.9 mg/s during a 2006 sampling after a large series of storms (Parsons, *in prep*.). During this sampling, nitrate loading rates at the downstream location within Olema Marsh plummeted to as low as 0.14 mg/s (Parsons, *in prep*.). Nitrites were generally not detected (<0.05 mg/L), except for one slightly elevated observation (0.07 mg/L) at the downstream location that did not exceed Basin Plan standards (RWQCB 1995a; Parsons, *in prep*.). Ammonia has not been detected (detection limit < 0.2 mg/L), and total dissolved phosphates generally ranged from non-detectable (<0.2 mg/L) to 0.35 mg/L (Parsons, *in prep*.). No clear upstream-downstream trend was apparent, but often concentrations were higher at the downstream end of the marsh (Parsons, *in prep*.). Slightly elevated concentrations of phosphates observed in Olema Marsh may result either from re-suspension of phosphates in sediments, excretion by aquatic organisms, or influx from some outside source of phosphates such as leaking septic systems (Parsons, *in prep*.).

Fecal Coliform

Tomales Bay. For decades, fecal coliform has been used as an indicator for the presence of pathogenic bacteria that could negatively affect human and wildlife health. Pathogenic bacteria are typically transmitted through human and animal feces, which enter streams and other water bodies either directly through cattle being in creeks or boats discharging sewage or indirectly through leaking septic systems or sewage treatment facilities. Because of the potential impact that bacteria have on shellfish production, research and monitoring for pathogens has been more extensive than that for nutrients. As early as 1967, the Pacific Marine Station and NMWD found that Tomales Bay had fecal coliform levels that were high during the winter runoff periods (Smith et al. 1971 *in* TBWC 2002). Since then, several intensive studies on bacteriological water quality of the Bay and its tributaries have been conducted over the past 28 years, which were summarized in the Staff Report for the pathogen TMDL (Ghodrati and Tuden 2005). These studies include:

- A 1974 shellfish and water quality study by the California Department of Health and Human Services (Sharpe);
- A shoreline and watershed water quality survey carried out in 1976-1977 and 1977-1978 by the RWQCB;
- A sanitary survey conducted by DHS;
- A pilot study conducted by DHS in the winter of 1994–95 to test sampling methods and locations for the 1995–96 study;
- A RWQCB-funded study conducted in 1995–96 by DHS and the RWQCB, under the auspices of the Tomales Bay Shellfish Technical Advisory Committee (TBSTAC); and
- A second RWQCB-funded study conducted in 2001 by the RWQCB and TBSTAC with assistance from the Seashore.

The results of these studies indicate that Tomales Bay and its tributaries have exceeded shellfish and water quality standards over the last three decades (Ghodrati and Tuden 2005). In 1974, DHS designed a study (TBSTAC 2000 *in* Ghodrati and Tuden 2005) to determine the water quality of Tomales Bay and tributary streams during wet weather conditions and relate the results to the bacteriological quality of the shellfish grown in the Bay. Shoreline samples showed elevated total and fecal coliform levels at numerous stations, which were attributed to the possibility of shoreline drainage, tributary streams entering the Bay, and possible failing septic systems. The study concluded that the high coliform counts were due to contribution of wastes by upstream dairies and, in lower Keyes Creek, from raw sewage discharges from the town of Tomales.

The RWQCB conducted a shoreline and tributary sampling survey during the winters of 1976–77 and 1977–78 (TBSTAC 2000 *in* Ghodrati and Tuden 2005), to evaluate the effectiveness of the RWQCB's recent requirements for dairy waste practices. Stream conditions improved for areas in which dairies had come into compliance with the minimum guidelines, although none of the shoreline or stream stations sampled met coliform objectives for water contact and non-contact recreation following periods of rainfall. Stream stations showed decreases in coliform between 1976–77 and 1977–78 following implementation of the minimum guidelines. The report also concluded that sewering of the town of Tomales in June 1977 resulted in decreased levels of coliform in Keyes Creek downstream of developed areas.

In 1980, the Food and Drug Administration (FDA), to determine the degree of pollution and the recovery rate of the Bay during periods of rainfall, conducted a sanitary survey from February 24 through March 12 (TBSTAC 2000 *in* Ghodrati and Tuden 2005). The results of this study showed that the shellfish market standard for fecal coliform was exceeded in all Bay water quality stations during wet periods. The dry period samples met the standard, with the exception of stations at the head of the Bay and near the mouth of Walker Creek. Seven out of eight shellfish samples exceeded the market standard. Fecal coliform densities in the streams during dry weather were equal to sewage from about 150 to 200 people. During wet weather, fecal coliform densities increased to the equivalent of sewage from 1,500 to 2,000 people or 500 to 700 cows. The highest loadings following rains revealed a bacterial equivalent of 40,000 to 50,000 people or 15,000 to 20,000 cows. The 1980 study concluded that the portions of the Bay most seriously affected by pollution from rainfall and runoff were the head of the Bay (Millerton Point south) and the Walker Creek delta. Rural and livestock sources of nonpoint pollution were considered to be the most likely cause of high fecal coliform densities in the Bay.

The pilot study conducted by DHS in the winter of 1994–95 was a prelude to the study during 1995–96 (TBSTAC 2000 *in* Ghodrati and Tuden 2005). Both of these studies were initiated as a result of Tomales Bay being listed as threatened under the Shellfish Protection Act and the formation of TBSTAC. The data from the pilot study support the theory that the major source of fecal contamination to the Bay is rainfall-related runoff from the tributaries. Two seasonal patterns of fecal coliform densities were observed: 1) sites that showed declining fecal coliform densities throughout the winter, suggesting a nonrenewable source of coliforms, and 2) sites that exhibited high fecal coliform densities throughout the season, suggesting a renewable source.

Following completion of the pilot study, the RWQCB and DHS conducted an intensive RWQCB-funded study of bacteriological and pathogen levels in the water of Tomales Bay and its watershed (TBSTAC 2000 *in* Ghodrati and Tuden 2005). As before, bacterial densities usually exceeded the standards within the first one or two days of each rainfall event, then, typically decreased to acceptable levels by the last day of sampling. Fecal coliform levels in the middle portion of Tomales Bay were generally lower than either the outer- or inner-bay regions, although all Bay stations experienced elevated concentrations of fecal coliforms immediately following rainfall. Consistently high bacterial levels were detected during most of the study at sites within the Walker/Keyes/Chileno Watershed and along the eastern shoreline watershed. Slightly lower concentrations of fecal coliforms were detected throughout the Lagunitas and Olema subwatershed. In contrast, bacterial levels at the western shoreline watershed stations were generally 10 to 100 times lower than those from all other subwatersheds. The highest loadings estimated were within the Walker/Keyes/Chileno and the Lagunitas and Olema subwatersheds. Within the Lagunitas/Olema Watershed, Lagunitas Creek contributed the largest share of the fecal load, followed by Olema Creek. The Bear Valley drainage contributed the lowest loadings for this Subwatershed.

In the winter of 2000–2001, the Water Board, in conjunction with TBSTAC and the Seashore, designed and conducted a study with the purpose of implementing some TBSTAC recommendations from the 1995–96 study. This study looked at both fecal coliform and *E. coli* as indicators for the presence of pathogens through both one-time and repeated measurements throughout three storm events, with repeated *E. coli* sampling used to estimate total loading rates for some of the sampling locations. Throughout the three wet-weather sampling events, the fecal coliform levels for all watershed and Bay station samples significantly exceeded the designated water quality objectives for shellfish harvesting waters and, in most cases, for contact and noncontact water recreation (RWQCB 2001). In general, fecal coliform levels remained high during all rainfall events sampled in all watersheds, typically increasing during the second day of each wet-weather sampling event (RWQCB 2001). Intensive time series sampling conducted on Olema Creek by the Seashore as part of this study showed that bacteria loading as represented by *E. coli* closely tracked stream discharge in terms of the rise and fall in flows, although there was often a two-hour lag in this system between peak stream discharge and peak *E. coli* levels (Ketcham 2001).

Of the inner Bay station samples, the highest fecal coliform levels were consistently detected at the inner Bay Station 1 (located south of the Tomales Bay Oyster Company lease area), which is closest to the inlet of Lagunitas and Olema Creeks (RWQCB 2001). The lower Walker Creek subwatershed contributed the highest one-time and highest overall instantaneous fecal coliform loadings (RWQCB 2001). Lower and upper San Geronimo Creek subwatersheds, which are tributaries to Lagunitas Creek, and lower (7.46×10^{13}) and upper Lagunitas Creek (5.13×10^{13}) ranked as the second and third and fifth and sixth largest contributors, respectively, in terms of instantaneous fecal coliform loading rates (RWQCB 2001). The Keyes Creek and Olema Creek subwatersheds recorded the lowest instantaneous fecal coliform loadings, with Olema Creek estimated at 8.67×10^{12} (RWQCB 2001). While pathogens concentrations are often higher in Olema Creek than Lagunitas Creek, the greater volume of stream discharge in Lagunitas Creek increases the loading potential of Lagunitas Creek relative to Olema (Ketcham 2001). In terms of total loading, Walker Creek again had the highest loading rates per day (3.97×10^{14}), followed by Lagunitas Creek (8.66×10^{13}) and Olema Creek (7.53×10^{13}; RWQCB 2001).

Results of the 2000-2001 study support results from the pilot study, which suggested either the presence of a renewable source or the introduction of new sources of fecal coliform throughout portions of the watershed (RWQCB 2001). As with many other previous studies, the 2000-2001 report speculated that agricultural sources are one of the major contributors of pathogens to Tomales Bay, particularly as the watersheds with the highest concentrations and loadings are primarily agricultural (RWQCB 2001). The RWQCB pointed to runoff from animal pastures (containing manure) and failing onsite sewage disposal systems or as some of the potential new or renewable sources of fecal coliform (RWQCB 2001). In another 2001 study, researchers found that concentration and loading of fecal coliform in creeks near a representative dairy was three times higher than that from a control watershed (Lewis et al. 2001). However, high levels of fecal coliform observed in San Geronimo Creek, which is not heavily agricultural, and Point Reyes Station storm drains indicates that developed areas cannot be discounted as a source (Ketcham 2001).

While most previous studies loosely refer to dairy and beef cattle operations as a primary source of pathogens, the 2001 study by Lewis and colleagues (2001) attempted to better define which portions of agricultural operations might be causing problems. Results appeared to point at dairy facilities rather than pastures – even manured pastures – as the highest potential agricultural contribution to pathogen loading (Lewis et al. 2001). The worst offenders for fecal coliform included manure stockpiles, feed lots, storm drains, and facility runoff, with potential fecal coliform loading from runoff from manure stockpiles and feed lots two to sometimes three orders of magnitude greater than loading from other parts of dairy facilities (Lewis et al. 2001).

Giacomini Ranch. Based on data collected between 2001-early 2006, fecal coliform concentrations were one to eight orders of magnitude greater in the Giacomini Ranch than in undiked wetlands in Tomales Bay and elsewhere (Parsons and Allen 2004a, Parsons, *in prep*.). Fecal coliform concentrations within of all Project Area sampling locations regularly to consistently exceeded TMDL standards proposed for the Lagunitas Creek watershed, with more than 50 to 75 percent of the sampling events having levels higher than 200 mpn/100 ml (Table 9, Parsons, *in prep*.). In 2005, the RWQCB finalized the Tomales Bay Pathogen TMDL, including adoption of fecal coliform concentration limits at the Green Bridge. Results of fecal coliform concentrations show that more than 80 percent of the sampling events did exceed the newly established TMDL concentration at the Green Bridge (95 mpn/100 ml) (Table 9, Parsons, *in prep*.).

In addition to the newly developed TMDL standards currently being finalized by the RWQCB, fecal coliform concentrations also consistently exceeded the Basin Plan standards for shellfish and municipal surface water supply beneficial uses and regularly to consistently exceeded standards for water contact recreation beneficial uses, with the Giacomini Ranch East Pasture and Lagunitas Creek exceeding 200 mpn/100 ml during more than 75 percent of the sampling events (Table 9, Parsons, *in prep*.). The Giacomini Ranch East Pasture also regularly exceeded standards for non-contact water recreation of 2,000 mpn/100 ml during more than 50 percent of the sampling events (Table 9, Parsons, *in prep*.). While both the East and West Pastures are used for dairying, use and land management is much more intensive in the East Pasture than the West Pasture, which is managed more as grazing land than a dairy pasture.

It should be noted that TMDL and Basin Plan standards are based on geometric means or medians for groups of samples collected over a specific sampling period, not single samples, but for the purposes of this document, both the number of objective exceedances by single samples and group means or medians were used to evaluate existing conditions within the Project Area. Most of the Basin Plan objectives focus on geometric means rather than arithmetic or the more traditional mean, because bacteria concentrations are calculated in a logarithmic –based scale that is more appropriately expressed as a geometric mean that divides the number of samples by the product rather than the sum of the values.

Based on concentrations for individual sampling events and mean and 90th percentile values during individual sampling events, the Giacomini Ranch East and West Pastures, Tomasini Creek, and Lagunitas Creek would consistently exceed the TMDL standards for Lagunitas Creek and the load-based allocation for Lagunitas Creek at the Green Bridge (Parsons, *in prep*.). Concentrations during individual sampling events would also consistently exceed Basin Plan bacteria objectives for shellfish and municipal water supply (<43 mpn/100ml), regularly to consistently exceed water contact recreation standards (<200 mpn/100ml), and infrequently to regularly (East Pasture only) exceed objectives for non-contact water recreation (<2,000 mpn/100ml; Table 9). Estimated mean concentrations for all sampling sites during the four-year sampling period would also exceed all Basin Plan objectives for beneficial uses.

As with nutrients, instantaneous loading rates for fecal coliform – or volume of coliforms relative to stream discharge -- remained consistently highest in Lagunitas Creek, although concentrations were almost lower than many other sampling locations. The estimated geometric mean for all sampling events at Lagunitas Creek Green Bridge during the sampling period averaged 14,125 mpn/s, with a median of 5,833 mpn/s (Parsons, *in prep*.). Similar to concentrations, the arithmetic mean for loading rates, which was estimated at 613,763 mpn/s, was skewed by some extremely high values, including a loading rate of approximately 10 million mpn/s during the April 2006 storm, which was a 2.25-year flood event (Parsons, *in prep*.). Some of the highest values for Giacomini Ranch creeks, drainages, and other water features or sources occurred several weeks after a large series of storms in May 2006, with instantaneous loading rates totaling 7,224 mpn/s for the 1906 Drainage, 10,691 mpn/s for Fish Hatchery Creek upstream of the Project Area, 494,371 mpn/s for Tomasini Creek within the Project Area (Parsons, *in prep*.). Estimated geometric mean loading rates during all four years of monitoring for creeks flowing into the Project Area ranged from 28.0 mpn/s for the 1906 Drainage to 202 mpn/s for Tomasini Creek, while portions of the Project Area affected by high concentrations of fecal coliforms in groundwater inflow and/or non-point source run-off had mean instantaneous loading rates ranging from as low as 1.46 mpn/s to as high as 458 mpn/s (Parsons, *in prep*.). Instantaneous loading rates for the East Pasture ranged from 262.3 mpn/s to 1,216.1 mpn/s, but, as was noted earlier, these areas are unable to discharge to downstream water bodies, so loading currently is negligible, with occasional discharges occurring during overbank flooding events and infrequent discharge of ditch water to Lagunitas Creek by the Giacominis (Parsons, *in prep*.).

Olema Marsh. Despite the fact that Olema Marsh is not directly within or below a dairy, fecal coliform concentrations were relatively high in the marsh, which is the downstream reach of Bear Valley Creek prior to its confluence with Lagunitas Creek (Parsons, *in prep*.). Fecal coliform levels consistently exceeded TMDL watershed and load-based standards for Lagunitas Creek and shellfish harvesting, municipal water supply, and water contact recreation beneficial use Basin Plan standards, with more than 75 percent of the sampling events having values greater than 200 mpn/100 ml (Table 9; Parsons, *in prep*.). The non-contact water recreation Basin Plan objective of 2,000 mpn/100ml was only infrequently exceeded (<15 percent of the sampling events; Table 9; Parsons, *in prep*.). For the period between 2004 – early 2006, fecal coliform concentrations averaged 2,403 mpn/100 ml (log mean), with a median of 736 mpn/100 ml and a 90^{th} percentile value of 5,284 mpn/100 ml (Parsons, *in prep*.). These values exceed all TMDL and Basin Plan bacteria standards or objectives (Parsons, *in prep*.).

As noted earlier, TMDL and Basin Plan standards are based on log or geometric means or medians for a group of samples collected over a specific time period. The estimated geometric mean instantaneous loading rates over the two years of sampling ranged from 1,692 mpn/s at the upstream sampling location to 1,241.3 mpn/s at the downstream sampling location, with the highest values of 5.3 million and 24,080 mpn/s, respectively, again being recorded in May 2006, several weeks after a large storm series (Parsons, *in prep*.). These values exceed all but the Non-contact Water Recreation standard of 2,000 mpn established in the Basin Plan (RWQCB 1995a).

Water Salinity and Quality and Wetland Functionality

The Project Area represents one of the largest interfaces between freshwater and saltwater in Tomales Bay. These estuarine transition zones are extremely dynamic areas with large variability in salinity conditions both between seasons and years. One of the unique phenomena often associated with estuarine transition zones is Null Zones or ETM, in which salinity or the interface between freshwater and saltwater can actually affect hydronamic processes and potentially increase trapping of sediments, nutrients, contaminants, and pathogens. These estuarine processes act in concert with fluvial ones in which sediment, nutrients, and contaminants are deposited onto floodplains during overbank flooding of floodwaters to increase the value of these transitional zones to water quality improvement.

Without more intensive monitoring, determining the degree to which Project Area is currently functioning to improve water quality – if at all – is extremely difficult. There appears to be some evidence of downstream reduction in nitrates and coliform during certain periods, although the trend was not consistent. Nitrate and fecal coliform concentrations in Lagunitas Creek almost universally dropped between Green Bridge and the northern levee of the Giacomini Ranch and on Fish Hatchery Creek between Sir Francis Drake Boulevard and the central portions of the West Pasture, but not on Tomasini Creek between Mesa Road and middle of East Pasture (Parsons and Allen 2004a, Parsons, *in prep*.). Tomasini Creek sometimes showed increases in nutrients and fecal coliform between upstream and downstream monitoring locations, suggesting continuing contribution from point and/or non-point sources (Parsons and Allen 2004a, Parsons, *in prep*.). Similar trends